



W72-14724

534

WATER POLLUTION CONTROL RESEARCH SERIES • 10125 DM • 9/71

PB 212 392

A SURVEY OF ALTERNATE METHODS FOR COOLING CONDENSER DISCHARGE WATER

SYSTEM, SELECTION, DESIGN, AND OPTIMIZATION

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151



ENVIRONMENTAL PROTECTION AGENCY • WATER QUALITY OFFICE

WATER POLLUTION CONTROL RESEARCH SERIES

The Water Pollution Control Research Series describes the results and progress in the control and abatement of pollution in our Nation's waters. They provide a central source of information on the research, development, and demonstration activities in the Water Quality Office, Environmental Protection Agency, through in-house research and grants and contracts with Federal, State, and local agencies, research institutions, and industrial organizations.

Inquiries pertaining to Water Pollution Control Research Reports should be directed to the Head, Project Reports System, Office of Research and Development, Water Quality Office, Environmental Protection Agency, Room 1108, Washington, D. C. 20242.

SELECTED WATER RESOURCES ABSTRACTS

INPUT TRANSACTION FORM

1. Report No.

2. Accession No.

W

72-14724

4. Title A SURVEY OF ALTERNATE METHODS FOR COOLING
CONDENSER DISCHARGE WATER--SYSTEM SELECTION, DESIGN,
AND OPTIMIZATION,

5. Report Date

8. Performing Organization
Report No.

7. Author(s)

~~Smith, R. M.~~ Maulbetts, J. S.

10. Project No. EPA Program

16130 DHS 8/71

9. Organization

Dynatech R/D Company, Cambridge,
Massachusetts

11. Contract/Grant No.

12-11-173

12. Sponsoring Organization

13. Type of Report and
Period Covered

15. Supplementary Notes Environmental Protection Agency, ~~Water Quality Office~~, Water
Pollution Control Research Series ~~NO-10100-DHS~~, January 1971, 108 p., 11 fig,
13 tab., 13 ref.

16. Abstract A computer program was written to calculate cooling system and power plant
cost and to determine the minimum total cost for a given set of parameters. Design
equations based on the use of water cooled condensers, cooling towers, open
cooling systems, operation of the power plant and the cooling system at various
ambient conditions or even operation of the power plant at up to five off-design
capacities have been provided for in the computer program, through which the minimum
total cost is calculated. (Smith-Texas)

(See also W72-06616, W72-06617,
and W72-06830)

17a. Descriptors *Power plants, *Computer programs, *Heat exchangers, *Water cooling,
Water costs, Cost analysis, Design *Electric power costs,
Optimization, *Thermal pollution, Waste water
treatment

17b. Identifiers

Copy available from GPO Sup Doc
, \$1.00 ; microfiche
from NTIS as PB 212 392, \$0.95.

05D,06C

18. COWEN Field & Group

19. Availability

19. Security Class.
(Report)

21. No. of
Pages

Send To:

20. Security Class.
(Page)

22. Price

WATER RESOURCES SCIENTIFIC INFORMATION CENTER
U.S. DEPARTMENT OF THE INTERIOR
WASHINGTON, D. C. 20240

Richard M. Smith, Jr.

Texas Univ, Austin

ia

A SURVEY OF ALTERNATE METHODS
FOR COOLING CONDENSER DISCHARGE WATER
SYSTEM, SELECTION, DESIGN, AND OPTIMIZATION

by

DYNATECH R/D COMPANY
A Division of Dynatech Corporation
Cambridge, Massachusetts 02139

for the

WATER QUALITY OFFICE
ENVIRONMENTAL PROTECTION AGENCY

Project No. 16130 DHS
Contract No. 12-14-477

January, 1971

ib

EPA Review Notice

This report has been reviewed by the Water Quality Office, EPA, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
1	INTRODUCTION	1
1.1	Overall Program Goals	1
1.2	Scope of Task I	1
1.3	General Method	3
2	POWER PLANT MODEL	6
2.1	General Description	6
2.2	Input Data	6
2.3	Preparation of Input Data Cards	9
2.4	Test Data	11
2.5	Power Plant Calculations in the Main Program	12
2.6	Program Optimization	17
3	ONCE-THROUGH COOLING	19
3.1	General Description	19
3.2	Assumptions	19
3.3	Basic Equations	20
3.4	Plume Analysis	22
3.5	Flow Diagram	27
3.6	Results	27
4	COOLING POND	35
4.1	General Description	35
4.2	Assumptions	35
4.3	Basic Equations	36
4.4	Flow Diagram	36
4.5	Results	36
5	MECHANICAL DRAFT WET COOLING TOWER	44
5.1	General Description	44
5.2	Assumptions	44
5.3	Basic Equations	45
5.4	Flow Diagram	49
5.5	Results	49
6	NATURAL DRAFT WET COOLING TOWER	54
6.1	General Description	54
6.2	Assumptions	54
6.3	Basic Equations	55
6.4	Flow Diagram	56
6.5	Results	56
	REFERENCES	62
	APPENDIX	65

Section 1

INTRODUCTION

1.1 Overall Program Goals

In December 1968, Dynatech R/D Company undertook a program for the Federal Water Quality Administration (then the FWPCA) with the ultimate aim of performing a survey and economic analysis of alternate methods for cooling condenser discharge water from thermal power plants. The first phase of this program was to consist of a systematic gathering of present state-of-the-art information in the areas of large scale heat rejection equipment, power plant operating characteristics, and total community considerations. The second phase of this program was to consist of work in the areas of:

1. Selection of input parameters and optimization criteria.
2. Limitations and advances in heat rejection units.
3. Extensive modifications of present power cycles.
4. Advanced total community concepts.

This report will document the results of Phase II, Task I of this program.

1.2 Scope of Task I

The first task of the second phase of this program has as an overall goal the quantification of cooling system costs as a function of various parameters, the definition of the interface requirements between the power plant and the cooling system, and the optimization of the total power cost.

A previous task, as reported in July 1969, (Ref. 1) presented, in detail, considerations of alternate methods of transferring large quantities of rejected heat to the atmosphere. The results of this analysis led to the expected conclusion that, for a given heat level and ambient conditions, the size and cost of the heat rejection equipment decreases with an increase in process side temperature. This cost relationship is shown as curve A in Figure 1.1.

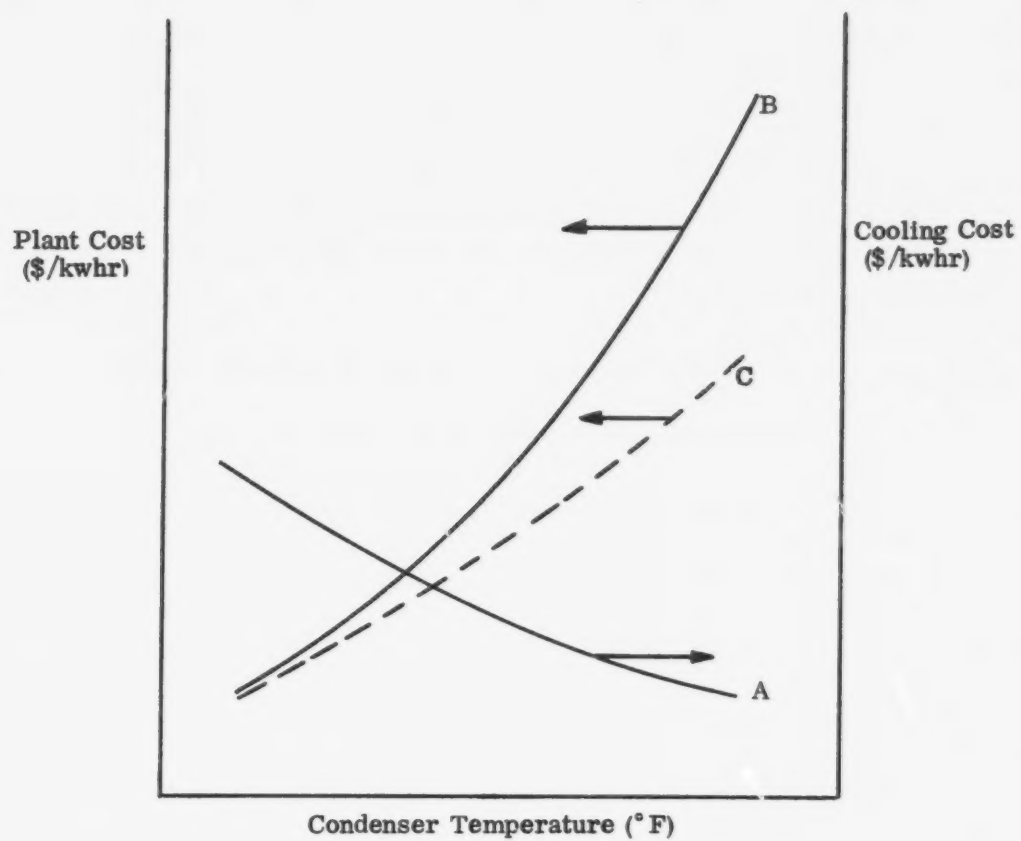


Figure 1.1. System Cost Versus Condenser Temperature

A later task, as reported in May 1970 (Ref. 2), described, in detail, the increase in power plant cost as a result of an increase in condenser temperature. This type of relationship is shown as curves B and C in Figure 1.1. Curve B may be thought of as representing an existing power plant forced to operate at a higher than design condenser temperature while curve C represents a possible locus of costs for plants designed for various condenser temperatures.

The goal of this task then is to quantify these curves, and to find a means of obtaining the minimum of the sum of the two costs for a wide range of ambient conditions and power plant parameters.

1.3 General Method

The general method of approach to this task has been the development of a computer program for the calculation of both cooling system and power plant costs and the determination of the minimum total cost for a given set of parameters. To this end, the effect of various design parameters have been studied to determine which have significant effects on the performance of the various cooling schemes and which parameters are important to the calculation of power plant costs. Design equations based on these parameters have been developed for the cooling systems and power plant, and incorporated into a computer program through which the minimum total cost is calculated.

A number of options are open to the user of the program such as full time or part time use of the cooling system, an open or closed cooling system, a specified or "designed" condenser, and variable ambient conditions. Also available is the ability to match projected power plant operation at different capacities over varying time periods.

Part time use of the cooling system is represented in Figure 1.2 and is applicable only to cooling systems that use a water cooled condenser such as cooling towers and cooling ponds.

An open cooling system, or "topping" operation is shown in Figure 1.3 and is again applicable only to cooling systems that use a water cooled condenser.

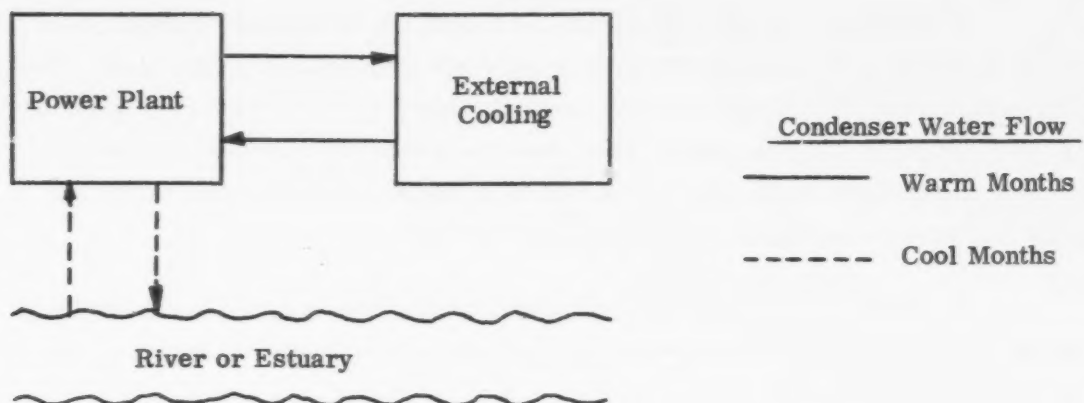


Figure 1.2. Part Time Use of External Cooling

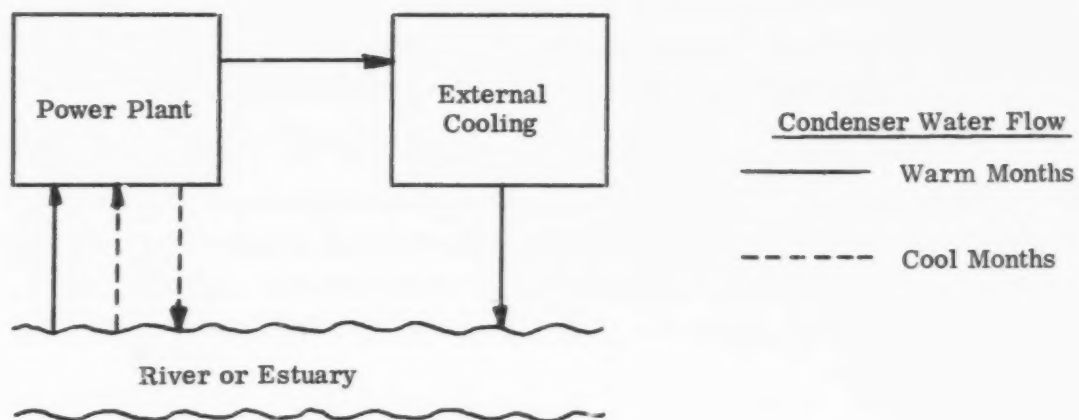


Figure 1.3. Open or Topping Cooling System (Shown as seasonal operation--can be used as full time open system also)

The water cooled condenser, as part of the external cooling system, may be specified or it will be "designed" by the program. This provides the option, for existing power plants that must have external cooling systems added, of either building an oversized external system to match the existing condenser or rebuilding the condenser such that the external cooling system and the condenser are matched and of minimum cost. Depending on the particular power plant, either method may result in the least overall cost.

Operation of the power plant and the cooling system at various ambient conditions for different periods of time has been provided for in the program. This is because cooling systems are usually designed for adverse and seldom occurring ambient conditions and do not operate under these extreme conditions most of the time. The program accounts for this in that it "designs" a cooling system for a given set of ambient conditions (usually specified as the most severe) but calculates operating costs of both the cooling system and power plant for up to five other sets of ambient conditions with a specified operating time per year for each.

Operation of the power plant at up to five off-design capacities for a specified number of hours per year has been provided in the program and is necessary to simulate actual power plant practice. The disadvantage to this is that plant operating characteristics (heat rate and auxiliary power) often are quite different for off design operation, and therefore must be specified for each capacity used. This is simplified somewhat, however, by available data such as contained in GE 2050B, included in Reference 2.

The remainder of this report, which describes the computer program, is divided into five sections. The first section describes the model of the power plant and the input data that is required. The following sections provide brief descriptions of the input (interface) requirements for each cooling system, review the general computational procedures, and describe the output. The details are obtainable from the program listings themselves (included in the appendix) which contain "comment" cards for ease of interpretation. A glossary of variable names for the whole program is also provided in the Appendix.

Section 2

POWER PLANT MODEL

2.1 General Description

As indicated in Section 1, the total design and optimization program consists of providing a mathematical description of the operating characteristics and system costs of the power plant itself, a similar model for alternative cooling schemes, and a means of interfacing these two subsystems and computing the total cost. Various combinations are then searched to find a minimum cost solution.

The first part of this program contains not only the mathematical description of power plant operation but it is also the control program which provides the interface information between the plant and the cooling system. This is indicated in a generalized flow chart of the program in Figure 2.1.

Basically, the "Power Plant Model" carries out two functions. First, it receives and manipulates all of the required input information to the optimization program. These inputs include such items as plant design capacity, projected load demands, plant efficiency ratings, projected cooling requirements, expected ambient conditions, and relevant economic data. A complete listing is given in Section 2.2. These input data are then manipulated to put the data into a form directly useful in the forthcoming computations. This portion of the model is contained in the first part of the main program.

The second function of the Power Plant Model is accomplished in subroutine PAFCST, an operational subroutine, which simulates power plant operation and provides heat rejection requirements and plant cost information to the cooling system subroutines.

2.2 Input Data

The data describing the power plant and the operation of it are read in the first portion of the program and, in order of input, are as follows:

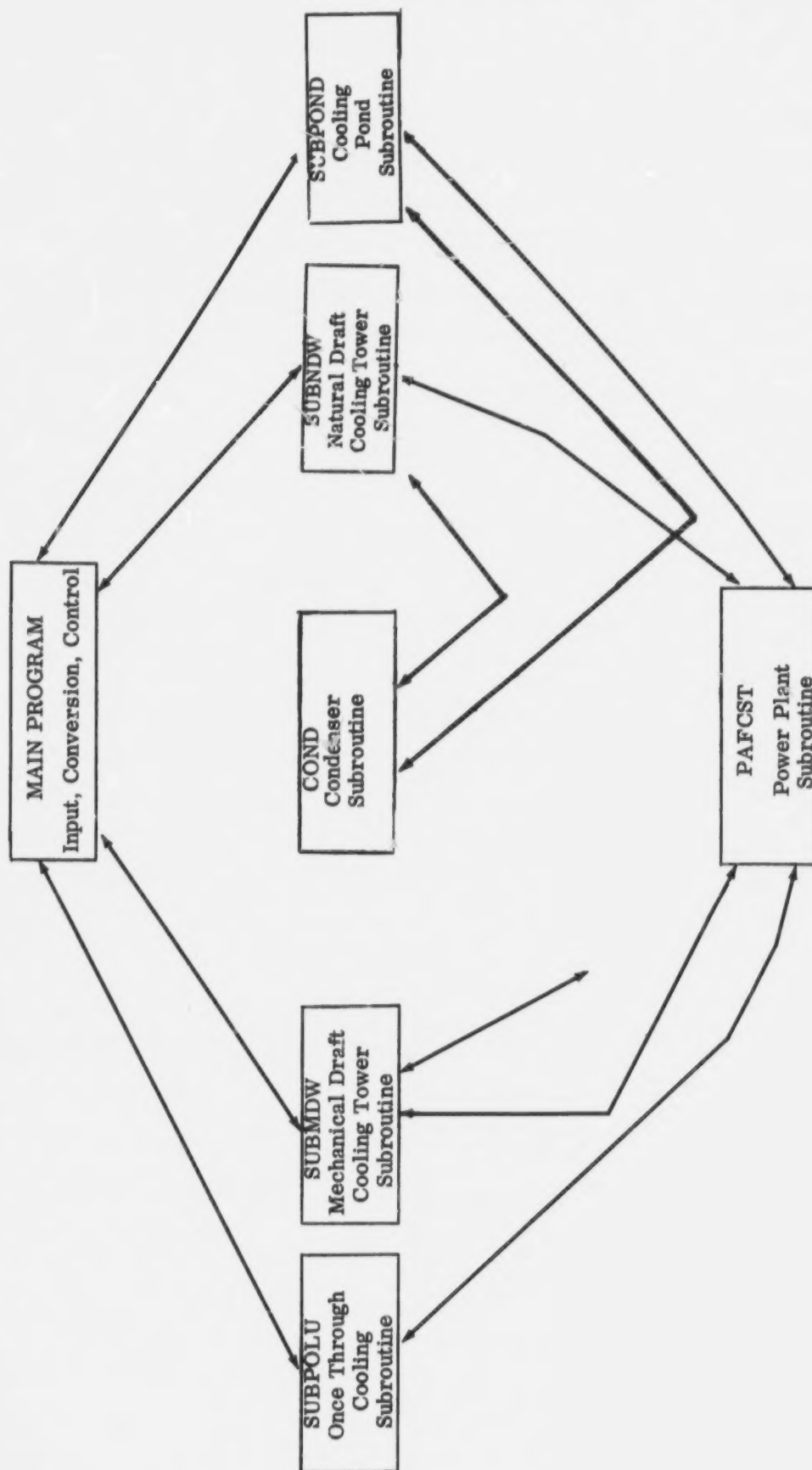


Figure 2.1

<u>Variable</u>		<u>Description</u>
PSIZE	-	Power plant size--the maximum electrical output of the plant and the size for which the cooling systems are to be designed (Mwe).
CCPKW	-	Power plant capital cost including a standard once through condenser (\$/kw).
ANFCR	-	Annual fixed charge rate (%/yr).
FUCST	-	Fuel cost (¢/million Btu).
PRPAGR	-	Land cost (\$/acre).
NCAPS	-	Number of different plant capacities for which heat rate data is supplied (maximum of 5 excluding design capacity).
CAP(I)	-	Various plant capacities (%/100).
TOTLD(I)	-	Total loading--number of hours per year that the plant operates at each capacity (hrs/yr).
COLPCT(I)	-	Cooling percent--percent of the total operating time at each capacity (TOTLD(I)) that the cooling system is used. (%/100).
NHRPTS(I)	-	Number of heat rate points--the number of condenser pressures and corresponding heat rates to be input for each capacity.
PCMIN(I)	-	Minimum condenser pressure at each capacity (in. Hg.).
PCMAX(I)	-	Maximum condenser pressure at each capacity (in. Hg.).

<u>Variable</u>	<u>Description</u>
HRP(I, J)* -	Condenser pressure for each heat rate at each capacity (in. Hg.) (do not have to include PCMAX(I) and PCMIN(I)).
TURBHR(I, J)* -	Turbine heat rate corresponding to each condenser pressure, HRP(I, J), for each capacity (Btu/kwhr).

The following input data pertain more to the cooling systems than to the power plant but are included here since they are read in the same part of the program as the power plant data.

TDB	-	Design ambient dry bulb temperature (° F)
TWB	-	Design ambient wet bulb temperature (° F)
TAVH2O	-	Design available water temperature (° F)
PCBASE	-	Base condenser pressure--a base average condenser pressure at which the plant would operate if external cooling were not required (in. Hg.).
WIND		Design wind velocity (MPH)
RAD		Design radiation intensity (Btu/ft ² /day)
NH2O	-	Type of cooling water to be used in the cooling system -1 = Seawater Ø = Untreated fresh water +1 = Treated fresh water
NTAMB	-	Number of different ambient temperatures.
TAMDB(I)	-	Various ambient dry bulb temperatures (° F)
TAMWB(I)	-	Various ambient wet bulb temperatures (° F)

*These values are obtained from General Electric Heat Rate Tables (Ref. 2) or other similar data.

<u>Variable</u>		<u>Description</u>
TAMRV(I)	-	Various river temperature($^{\circ}$ F)
AMWIND (I)	-	Various wind velocities (MPH)
AMRAD (I)	-	Various radiation fluxes (Btu/ft ² /day)
PCTAMB(I, J)	-	Percent of the cooling system use time, COLPCT(I) x TOTLD(I), at each capacity, that the cooling system operates at the specified ambient temperatures, TAMDB(I) and TAMWB(J) (%/100).
WIDTH	-	Width of river or estuary (ft).
NSYSOP	-	Type of cooling system operation 0 = closed cycle operation 2 = topping
NSPCON	-	Whether or not the condenser is specified 0 = no 1 = yes
TDISMX	-	Maximum water discharge temperature (only if topping used) ($^{\circ}$ F)
UOVALL	-	Overall heat transfer coefficient for the condenser (only if condenser is specified) (Btu/hr-ft ² - $^{\circ}$ F).
AREAC	-	Total heat transfer area (only if condenser is specified) (ft ²)
3PFLOW	-	Condenser water flow (only if condenser is specified) (lbm/hr)
NSUBS(I)	-	Controls which of the cooling subroutines is called. If NSUBS (I) is zero, the <u>I</u> th subroutine is not called.
	<u>I</u>	<u>Subroutine</u>
	1	Listing of input data (part of main program)
	2	Once through cooling (SUBPOLU)
	3	Cooling Pond (SUBPOND)
	4	Mechanical Draft Wet Tower (SUBMDW)
	5	Natural Draft Wet Tower (SUBNOW)

2.3

Preparation of input data cards

All cards are required for each set of input conditions, although all cooling options may be run with one set of plant and ambient data. FORTRAN format specifications are shown for each input card required.

Card 1: PSIZE, CCPKW, ANFCR, FUCST, PRPAGR, NCAPS (5F10.0,I10)

Card 2: CAP (I), I = 1,5 (5F10.2)

Card 3: TOTLD (I), I = 1,5 (5F10.0)

Card 4: COLPCT (I), I = 1,5 (5F10.2)

Card 5: NHRPTS (I), I = 1,6 (6I10)

Card 6: PCMIN (I), I = 1,6 (6F10.2)

Card 7: PCMAX (I), I = 1,6 (6F10.2)

Cards 8-X: NNCAP sets (a set for each capacity, plus one if design data are input. See Section 2.4) of two cards each:

card A: HRP (SET NUMBER, J), J = 1,6 (6F10.2)

card B: TURBHR (SET NUMBER, J), J = 1,6 (6F10.0)

Card X + 1: TDB, TWB, TAVH20, PCBASE, WIND, RAD, NH20,
NTAMB (6F10.0,2I10)

Card X + 2: TAMDB (I), I = 1, NTAMB (5F10.0)

Card X + 3: TAMWB(I), I = 1, NTAMB (5F10.0)

Card X + 4: TAMRV (I), I = 1, NTAMB (5F10.0)

Card X + 5: AMWIND (I), I = 1, NTAMB (5F10.0)

Card X + 6: AMRAD (I), I = 1, NTAMB (5F10.0)

Cards X + 7-Y: NCAPS cards each with PCTAMB
(SET NUMBER, J), J = 1, NTAMB (5F10.2)

Card Y + 1: WIDTH, NSYSOP, NSPCON, TDISMX, UOVALL,
AREAC, SPFLOW (F10.0,2I10,4F10.0)

Card Y + 2: NSUBS (I), I = 1,5 (5I10)

2.4 Test Data

Four sets of input data have been used to obtain cooling system costs. These four data sets have been designated SUBD1, SUBD2, SUBD3, and SUBD4. All four sets contain the same power plant data and ambient temperature but each describes a different type of cooling system operation as described below.

- SUBD1 - Condenser is specified and the cooling system is used for topping.
- SUBD2 - Condenser is specified and the cooling system is a closed system.
- SUBD3 - Condenser is "designed" and the cooling system is used for topping.
- SUBD4 - Condenser is "designed" and the cooling system is a closed system.

Listings of these four sets of data are included in the Appendix, and the input data printout, when SUBD1 is used, is shown in Table 2.1.

*Number of cards depends on number of capacities specified.

Table 2.1

-----PRINTOUT OF INPUT DATA-----

PSIZE	CAP \$	ANFCR	FUEL \$	PRPAGR
200	150	.12	10	1000

CAPACITIES AND CORRESPONDING DATA
(EXTRA VALUES ARE DESIGN DATA)

CAPACITY -	1.00	.80	.60	.25	0	
HRS/YEAR -	5150	1750	800	700	360	
PCT COOLING -	.40	.70	.50	.30	.15	
MIN P COND -	1.50	1.00	1.00	1.00	1.00	1.50
MIN T COND -	91.72	79.04	79.04	79.04	79.04	91.72
MAX P COND -	3.50	4.00	4.00	4.50	4.50	3.50
MAX T COND -	20.55	125.41	125.41	129.77	129.77	120.55
CAPACITY FACTOR = .82						
COOLING USE FACTOR = .75						

COND PRESS AND CORRESPONDING DATA AT EACH CAPACITY

CAPACITY = 1.00				
PRESSURE -	1.50	2.50	3.50	
T HEAT RATE -	7987	8037	8153	
CAPACITY = .80				
PRESSURE -	1.00	2.00	3.00	
T HEAT RATE -	7974	802	8174	
CAPACITY = .60				
PRESSURE -	1.00	2.00	3.00	3.50
T HEAT RATE -	8055	8195	8430	8543
CAPACITY = .25				
PRESSURE -	1.00	2.00	3.00	
T HEAT RATE -	8828	9381	9815	
CAPACITY = 0				
PRESSURE -	1.00	2.00	3.00	
T HEAT RATE -	0	0	0	

DESIGN VALUES (CAPACITY = PLANT SIZE)

PRESSURE -	1.50	2.00	2.50	3.00	3.50
T HEAT RATE -	8000	8009	8042	8089	8151
DRY BULB T	85	WET BULB T	75	WIND SPEED	10.0
				RADIATION	4000
AVAIL H2O T	75	TYPE AVAILABLE H2O	-1		
BASE P COND	1.50	BASE T COND	91.7		

Table 2.1 (Concluded)

VARIABLE AMBIENT TEMPERATURES

DRY BULB -	70	80	85
WET BULB -	60	70	70
RIVER -	60	65	70
WIND	10.0	10.0	10.0
RADIATION	4000	4000	4000

PERCENT OF COOLING SYSTEM TIME AT ABOVE
AMBIENT CONDITIONS

CAP = 1.00 -	.25	.25	.50
CAP = .80 -	.30	.30	.40
CAP = .60 -	.40	.30	.30
CAP = .25 -	.50	.25	.25
CAP = 0 -	0	0	1.00

RIVER WIDTH	TYPE COOLING (2=TCPPIG)	COND SPECIFIED (1=YES)
2000	2	1

MAX DISCHARGE TEMP = 85

CONDENSER SPECIFICATIONS

OVERALL U = 350
TUBE AREA = 2.760E 05
H2O FLOW = 4.200E 07

2.5 Power Plant Calculations in the Main Program

The first calculation that is performed in the main program, after the data are read, is to check that the total load duration hours per year equals 8760 hours (including 0 capacity operation), and that, for each capacity, the total percent of operating time at the various ambient conditions equals 100.

The design relative humidity, RH, and the variable ambient relative humidity, AMBRH(I), are then calculated from the wet bulb and dry bulb temperatures with the use of the Carrier equation (cf Ref. 3).

Following the calculation of the relative humidities is the quadratic curve fit of the heat rate points. The curve fit is necessary to provide continuous heat rate values, at the various plant capacities, for condenser pressures between the specified points. The actual curve fit is in terms of condenser temperature rather than pressure, so that the specified condenser pressure input data is first converted to saturation temperature. Also, immediately following this conversion, the maximum and minimum allowable condenser pressures and the base condenser pressure are converted to corresponding saturation temperatures.

If "design" heat rate data is not included in the input, then the program assumes that the 100 percent plant capacity data is to be used for design. This conversion is performed next in the program. Either 100 percent plant capacity data or "design" data must be specified for the program to run. Both may be specified since it may be desirable to "design" the cooling system to match plant operation under special conditions such as above rated capacity ("valves wide open", overpressure, and/or feedwater heaters shut down - see Ref. 2).

Plant capacity factor and cooling system use factor are calculated from the load data. The capacity factor is a measure of the use of the plant relative to its hypothetical maximum design use,

$$\text{CAPFAC} = \frac{\text{total kwhrs output in year}}{\text{maximum design output}} \text{ (plant at full design capacity for 8760 hours)}$$

The cooling system use factor is the average percent of plant output that is created while the cooling system is in use,

$$\text{USEFAC} = \frac{\text{kwhrs output with cooling system in use}}{\text{total kwhrs output in year}}$$

The capacity factor is used to adjust capital cost to be in terms of actual output (kwhrs) in a year, and the use factor is used to adjust cooling system operating cost to be in terms of total plant output in a year.

If the computer system on which the program is to be run cannot handle all the code necessary for the main program and each of the subroutines, the subroutines for cooling methods which will not be used can be omitted, and the references to them in the main program deleted.

2.6 Program Optimization

Following preliminary calculations in the main program, control is transferred to one of the operational subroutines, SUBPOLU, SUBPOND, SUBMDW, or SUBNDW, where the optimum cooling system design is determined. The method of optimization used in these subroutines is a complete search of all allowable combinations of the design variables. Obviously, however, when part of the cooling system is specified, such as the condenser, the design variables describing them are not varied.

In the general case, there are two temperatures that are varied to determine the optimum tower, the condenser temperature and the water discharge temperature from the tower or pond. The condenser temperature is set to the lowest possible value and tower costs are calculated for the full range of possible discharge temperatures. The condenser temperature is then increased by 1° F and the calculations made again for the range of discharge temperatures. The process is repeated until the condenser temperature has been increased to its maximum

prescribed value. During the whole process, each time a combination of variables resulted in a tower cost less than the preceeding lowest one, the variables were "saved" for future comparison. Therefore, after all combinations have been tried the "saved" combinations will be the least cost and therefore the optimum.

This optimization procedure is shown in more detail in Figures 3.2, 4.1, and 5.3.

2.7 Subroutine PAFCST (Power and Fuel Cost)

This subroutine, which is "called" by the cooling system subroutines, calculates auxiliary power cost, differential fuel cost, and heat rejected from the power plant for operation at a given capacity and condenser temperature.

At each capacity a base heat rate, HRBASE, is first calculated with the quadratic coefficients, HRCOF2(I), HRCOF1(I), and HRCOF0(I), and the base condenser temperature. The actual heat rate is then calculated at the desired condenser temperature and the heat rejected, QREJ calculated by

$$QREJ = (HEATR-3413) \times PSIZE \times CAP(I) \quad (2.1)$$

where HEATR = net heat rate - (Btu/kwhr)
 PSIZE = total rated plant output (Mw)
 CAP(I) = plant capacity of interest (%/100)

Boiler efficiency (stack heat loss) is not included in the above equation since the net heat rate used is defined as the heat added to the steam divided by the net power output.

The differential fuel cost is calculated by

$$\text{DELFC} = \text{FUCST} \times (\text{HEATR} - \text{HRBASE}) \quad (\text{mills/kwhr}) \quad (2.2)$$

where FUCST = fuel cost (¢/million Btu)
 HRBASE = base heat rate (Btu/kwhr)

The auxiliary power cost is calculated by

$$\text{PWCST} = \text{FUCST} \times \text{HEATR} + \frac{\text{CCPKW} \times \text{ANFCR}}{\text{CAPFAC} \times 8.76} \quad (\text{mills/kwhr}) \quad (2.3)$$

where CCPKW = plant capital cost (\$/kw)
 ANFCR = annual fixed charge rate (%/100)
 CAPFAC = capacity factor (%/100)

Section 3

ONCE-THROUGH COOLING

3.1 General Description

The calculations and logic for the design of a once-through cooling are contained in two subroutines, SUBPOLU and COND. Subroutine SUBPOLU contains most of the logic and about half of the cost calculations for this type of cooling. It is divided into two parts, a design section in which the cooling system costs are calculated for the design ambient conditions and power output, and an off-design section in which the operating costs are recalculated using the specified variable capacities and ambient conditions. The condenser may be specified as already existing, in which case the capital cost is not included in the total system cost.

Also included in subroutine SUBPOLU is a calculation and printout of river temperatures downstream of the plant. This includes both mixed river temperatures and plume temperatures, and plume width for a specified river. The equilibrium temperature and plume temperature are determined from data and equations taken from Reference 5.

Subroutine COND, which is also used by other cooling systems requiring a water cooled condenser, contains the basic design and cost calculations for the condenser itself.

3.2 Assumptions

Variables and equations for which numerical assumptions have been made in the subroutine are listed below, so that the cards may be changed if different numerical values are desired.

Variable (sequence or line #)Comments and/or Recommended ValuesSubroutine SUBPOLU

WIND (255)

QFLRIV (256)

DEPTH (257)

RAD (258)

4000 - 6000

PMPEF (259)

0.8 - 0.85

WCOFA (264)

Should be of the form used in Reference 5

WCOFB (265)

DT2 (293)

Need not correspond to (not used for) specified condenser

PLAC (306-310)

1.5, 1.25, 1.0 for seawater, untreated fresh, and treated fresh water, respectively.

PHEAD (315)

COSMAI (319)

Form of equation and percentages both assumed

Subroutine COND

PMPEF (1252)

0.8 - 0.85

UALL (1257-1261)

420., 340., and 250 correspond to treated fresh water, untreated fresh water, and sea water, respectively.

CONCST (1270)

Form and coefficients of equation assumed.

CHEAD (1276)

35.

3.3 Basic Equations

For the condenser the basic size equation for the total heat transfer area is

$$A_{COND} = \frac{Q_{REJ}}{U_{ALL} \times DTLGM} \quad (3.1)$$

where Q_{REJ} = total heat rejected (Btu/hr)
 U_{ALL} = overall heat transfer coefficient (Btu/hr-ft²-°F)
 $DTLGM$ = log mean temperature difference (°F)

The capital cost equation for the condenser, derived from data in References 7, 12, and 13 is

$$\text{CONCST} = 20. \times (1.05 \times \text{ACOND})^{0.9} \quad (\$) \quad (3.2)$$

Added to this is \$1/GPM for the cost of the water pumps.

The condenser system cost is the sum of the capital cost (capital charge per year) and the pumping costs, which are

$$\text{PMPCST} = \frac{\text{GPM} \times \text{PHEAD} \times .7457 \times \text{PWCST}}{3960 \times \text{PMPEF} \times \text{PSIZE} \times 1000} \quad (\text{mills/kwhr}) \quad (3.3)$$

where

- PHEAD = assumed frictional pumping head (ft)
- PWCST = power cost (mills/kwhr)
- PMPEF = pump efficiency (%/100)
- PSIZE = plant size (Mw)

The above three equations are contained in the subroutine COND.

In the subroutine SUBPOLU, other costs are added to the condenser system cost. These consist of the inlet and outlet water ducting costs, an additional pumping cost for this ducting, and a differential fuel cost obtained from the subroutine PAFCST, due to power plant operation at a condenser pressure higher than PCBASE.

If the condenser is specified, then, since the inlet water temperature is known, the condenser temperature and outlet water temperature may be determined by simultaneous solution of the following three equations. From the power plant subroutine PAFCST, we get

$$\text{QREJ} = f(\text{TC}) \quad (3.4)$$

In addition,

$$\text{QREJ} = \text{SPFLOW} \times (\text{T1} - \text{T2}) \times \text{C}_p \quad (3.5)$$

where SPFLOW = specified water flow (lbm/hr)
 T1 = outlet water temperature (° F)
 T2 = inlet water temperature (° F)
 Cp = specific heat of water = 1 (Btu/lbm-° F)

and

$$QREJ = UOVALL \times AREAC \times \frac{(T2 - TC) - (T1 - TC)}{\ln \left(\frac{T2 - TC}{T1 - TC} \right)} \quad (3.6)$$

where UOVALL = specified overall heat transfer coefficient (Btu/hr-ft²-° F)
 AREAC = specified heat transfer area (ft²)

T1, TC, and QREJ are the only three unknowns, but since the function f of Equation (3.4) is a quadratic curve fit, the simultaneous solution to the three equations is performed by trial and error, in subroutine SUBPOLU.

3.4 Plume Analysis

The final computations performed in subroutine SUBPOLU describe the spread and dissipation of the stream of condenser discharge water, or plume, after it is returned to the flowing river. As was indicated by Edinger and Geyer (Reference 5), even simple limiting models of the spread of warm light water into cold water defy a first-principles analysis at this time. Therefore, the approach taken was to define an arbitrary spreading function which described the increase in plume width with distance downstream of the outfall. This spreading function was prescribed to meet certain physical constraints. These were:

1. the plume width at the outfall was related to the overall width of the river by the ratio of the condenser discharge flow to the undisturbed river flow. That is

$$\frac{PLUMEW}{WIDTH} \text{ (at the outfall)} = \frac{QCON}{QFLRIV} \quad (3.7)$$

where

PLUME = width of plume (ft.)
WIDTH = total width of river (ft.)
QFLRIV = total river flow (ft³/sec)
QCON = condenser discharge flow (ft³/sec)

2. the spreading rate is of an exponential form.

3. the plume width approaches the total river width smoothly.

A spreading function which satisfies these criteria is

$$\text{PLUMEW} = \text{WIDTH} \times \left[1 - e^{-(A \times \text{XI} + \text{C1})} \right] \quad (3.8)$$

where

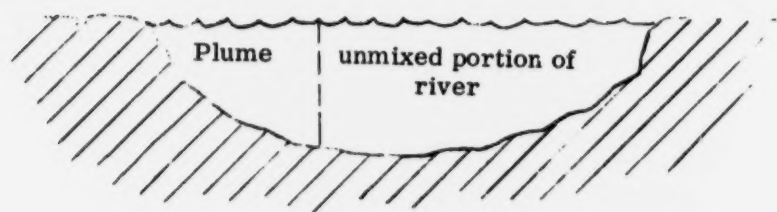
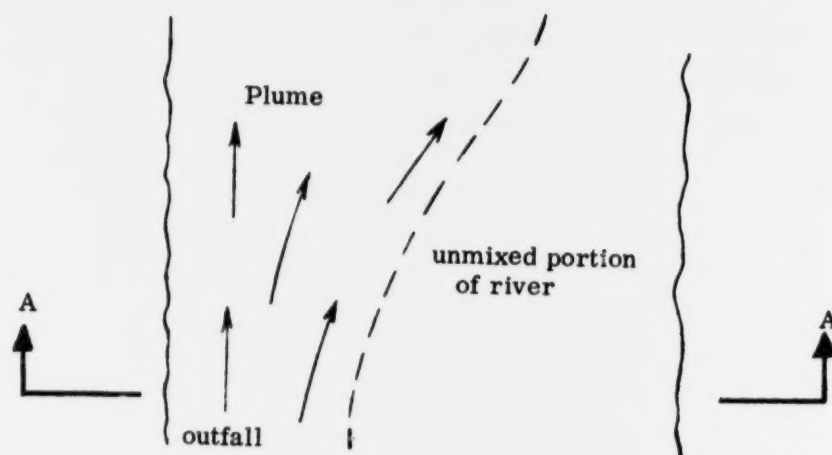
A = a constant which can be interpreted as an inverse mixing length (1/miles)
XI = distance downstream of the outfall (miles)
C1 = a constant evaluated so as to satisfy Equation 3.7 at XI = 0.

In order to obtain a reasonable approximation to some plume width data in Reference 5, the mixing length was chosen as $\frac{1}{A} = 2$.

Which yielded the final result

$$\text{PLUMEW} = \text{WIDTH} \times \left[1 - e^{-\left(\frac{\text{XI}}{2} + \text{C1}\right)} \right] \quad (3.9)$$

This results in a description which can be interpreted physically according to Figure 3.1, as a two-dimensional unstratified model.



View A-A

Figure 3.1 Schematic of Plume-River Flow

Both streams are subject to heat transfer with the environment and both approach the environmental equilibrium temperature exponentially as derived in Reference 5.

The temperature of the unmixed cold stream, TWREAL, is the easiest to specify since it is by definition unaffected by the plume and simply approaches the equilibrium temperature, TCALC, according to

$$TWREAL = TCALC + (TAVH20 - TCALC) e^{ALPHA1} \quad (3.10)$$

where

TWREAL = unmixed stream temperature (°F)

TCALC = equilibrium temperature (°F)

TAVH20 = temperature just upstream of plant (°F)

ALPHA1 = decay constant

$$= - \frac{XK \times XI}{DENSITY \times DEPTH \times VELREV} \text{ from Reference 5}$$

The temperature of the plume is most easily defined in terms of a mixed river temperature, TXDIST. The hypothetical temperature is the temperature which the river would be at any point if the plume and the unmixed portion were thoroughly mixed. This temperature, which also approaches the environmental equilibrium temperature, can be shown to be

$$TXDIST = TCALC + (TZERO - TCALC) e^{ALPHA1} \quad (3.11)$$

TXDIST = mixed river temperature at any downstream (°F)

where TZERO = mixed river temperature at the outfall (°F)

Therefore,

$$TZERO = \frac{QCON \times T1 + (QFLRIV - QCON) \times TREAL}{QFLRIV} \quad (3.12)$$

The plume temperature, PLUMT, is then computed on the basis of a simple energy balance from the mixed river temperature (Equation 3.11) and the plume flow rate (assumed proportional to plume width from Equation 3.9). Hence,

$$QFLRIV \times TXDIST = Q PLUM \times PLUMT + (QFLRIV - QPLUM) TWREAL \quad (3.13)$$

$$\frac{PLUMT - TWREAL}{TXDIST - TWREAL} = \frac{QFLRIV}{QPLUM} = \frac{WIDTH}{PLUMEW} \quad (3.14)$$

Then from Equation 3.9

$$\frac{PLUMT - TWREAL}{TXDIST - TWREAL} = \frac{1}{1 - e^{-(XI/2 + C1)}} \quad (3.15)$$

where

$$PLUMT = \text{plume temperature (}^{\circ}\text{F)}$$

3.5 Flow Diagram

Figures 3.2 and 3.3 contain the flow diagram for the subroutine SUBPOLU. Some minor calculations and program checks have been omitted for clarity.

3.6 Results

The results using the data of SUBD2 and SUBD4, described in Section 2, are shown in Tables 3.1 and 3.2.

The design values are printed first and consist of the following:

Q REJECT	-	The heat rejected from the plant by the condenser
T CONDENSER	-	The temperature of the condensing steam
CONDENSER FLOW	-	The condenser cooling water flow
PUMP POWER	-	The power required to pump the cooling water
EQUILIBRIUM TEMP	-	The equilibrium temperature corresponding to the design ambient conditions
RANGE	-	The cooling water temperature rise from inlet to exit.

The design costs are printed next. It should be pointed out here that since the various cooling subroutines use common printing subroutines, PRTDS1, PRTDS2, and PRTOD, there are a few quantities in each print out that are not applicable to the cooling system being described. Zeros (with no decimal point) are usually printed as the value of such quantities and the term "not applicable" will be used when describing the results. An example of such a quantity is the first design cost printed, the CAPITAL COST. The capital cost of the condenser is not printed out but it is included in the condenser system cost, described below.

The OPERATING COST result printed for this subroutine consists only of the extra pumping costs associated with the inlet and outlet water ducting for the condenser. Other pumping costs are included in the condenser system cost.

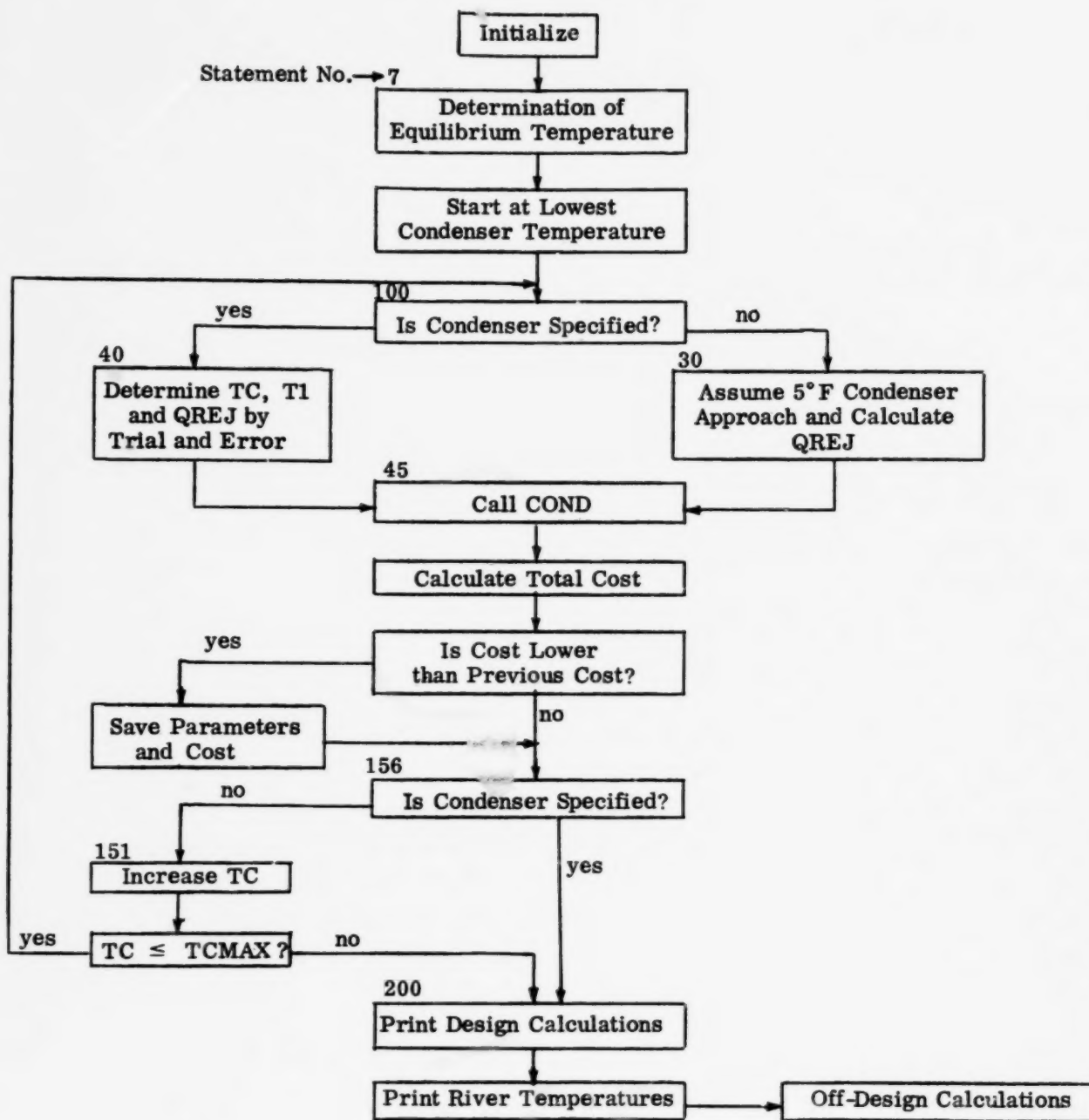


Figure 3.2 Flow Diagram for Design Portion of SUBPOLU

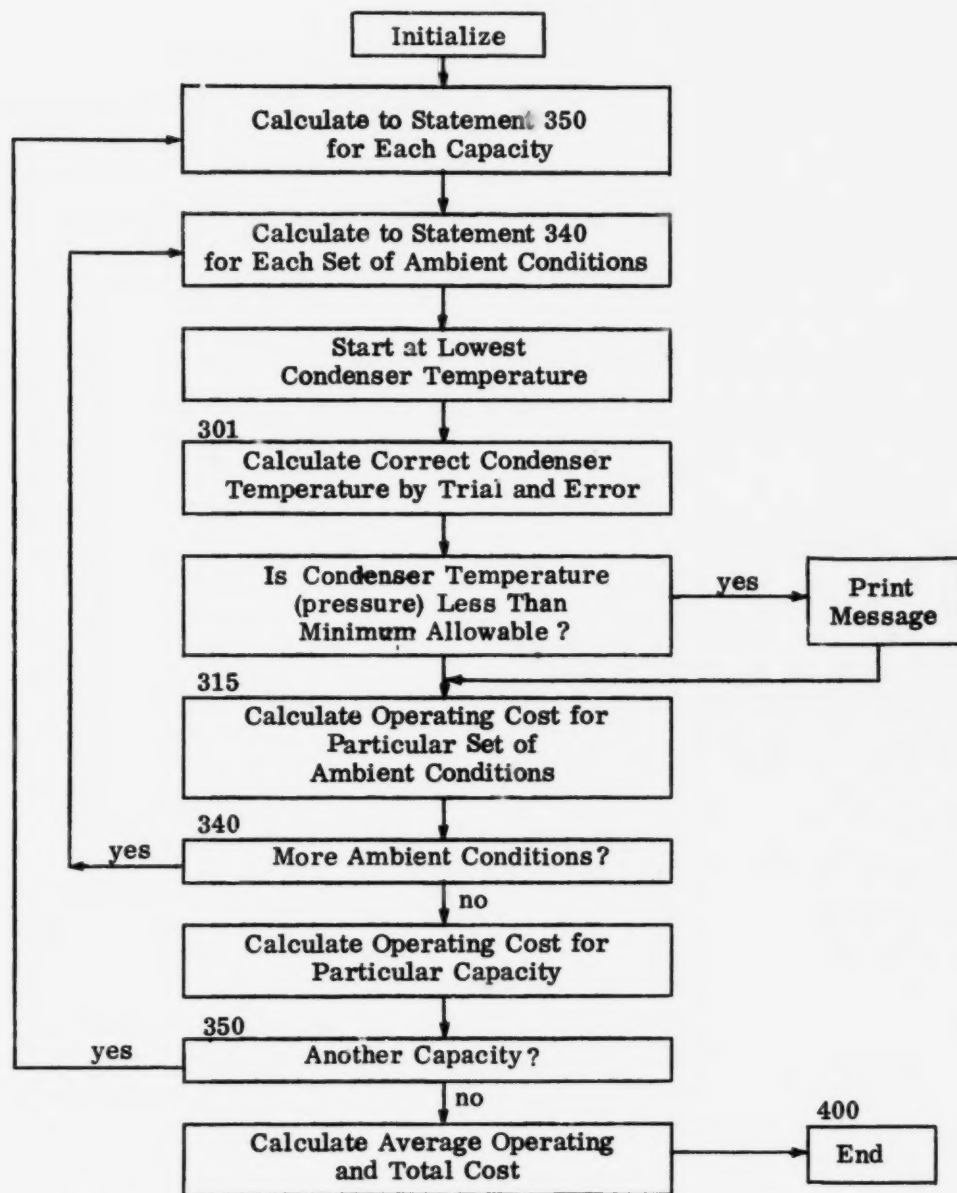


Figure 3.3 Flow Diagram for Off-Design Portion of SUBPOLU

Table 3.1
ONCE-THROUGH COOLING RESULTS USING SUBD2
(CONDENSER SPECIFIED)

-----STRAIGHT CONDENSER COOLING-----
(WITH UNTREATED FRESH WATER)

THE DESIGN VALUES AND COSTS ARE -

Q REJECT = 9.181E 08 BTU/HR AT T CONDENSER = 100
CONDENSER FLOW = 1.869E 02 CFS (4.200E 07 LB/HR) PUMP POWER = 1.325E 02 HP
EQUILIBRIUM TEMP = 86 RANGE = 22

CAPITAL COST = 0E 00 DOLLARS
CONDENSER AND PUMP COST = 0E 00 DOLLARS/KW
OPERATING COST = .002 MILLS/KW-HR
MAINTENANCE COST = .000 MILLS/KW-HR
CONDENSER SYSTEM COST = 0 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .000 MILLS/KW-HR

TOTAL SYSTEM COST = .002 MILLS/KW-HR

--RIVER TEMPERATURES--

DISTANCE-MILES	STREAM TEMP DEG.F NO PLANT MIXED		PLUME TEMP.-DEG.F	PLUME WIDTH-MI
0	75.00	75.58	96.86	.0101
1.0	75.66	76.21	77.01	.1552
2.0	76.29	76.81	77.11	.2432
3.0	76.88	77.38	77.52	.2965
4.0	77.45	77.92	77.99	.3289
5.0	77.98	78.43	78.47	.3485
6.0	78.49	78.91	78.93	.3604
7.0	78.97	79.37	79.38	.3677
8.0	79.42	79.80	79.81	.3720
9.0	79.86	80.22	80.22	.3747
10.0	80.26	80.61	80.61	.3763
20.0	83.35	83.56	83.56	.3788

Table 3.1 (Concluded)

VARIABLE AMBIENT CONDITIONS

FOR CAP = 1.00, T WB = 60, AND TC = 92
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = 1.00, T WB = 70, AND TC = 92
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = .60, T WB = 60, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = .25, T WB = 60, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = .25, T WB = 70, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = .25, T WB = 70, AND TC = 79

PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

WITH THE VARIOUS AMBIENT TEMPERATURES
THE COSTS ARE -

OPERATING COST = .001 MILLS/KW-HR
DIFFERENTIAL FUEL COST = -0.000 MILLS/KW-HR

TOTAL SYSTEM COST = .001 MILLS/KW-HR

Table 3.2
ONCE-THROUGH COOLING RESULTS USING SUBD4
("DESIGN" CONDENSER)

-----STRAIGHT CONDENSER COOLING-----
(WITH UNTREATED FRESH WATER)

THE DESIGN VALUES AND COSTS ARE -

Q REJECT = 9.454E 08 BTU/HR AT T CONDENSER = 120
CONDENSER FLOW = 1.059E 02 CFS (2.380F 07 LB/HR) PUMP POWER = 7.507E 01 HP
EQUILIBRIUM TEMP = 88 RANGE = 40

CAPITAL COST = 0E 00 DOLLARS
CONDENSER AND PUMP COST = 5.093E 00 DOLLARS/KW
OPERATING COST = .001 MILLS/KW-HR
MAINTENANCE COST = .001 MILLS/KW-HR
CONDENSER SYSTEM COST = .112 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .014 MILLS/KW-HR

TOTAL SYSTEM COST = .128 MILLS/KW-HR

--RIVER TEMPERATURES--

DISTANCE-MILES	STREAM TEMP DEG.F		PLUME TEMP.-DEG.F	PLUME WIDTH-MI
	NO PLANT	MIXED		
0	75.00	75.60	114.72	.0057
1.0	75.66	76.23	77.08	.1525
2.0	76.29	76.83	77.14	.2415
3.0	76.88	77.40	77.54	.2955
4.0	77.45	77.93	78.01	.3283
5.0	77.98	78.44	78.48	.3482
6.0	78.49	78.92	78.95	.3602
7.0	78.97	79.38	79.39	.3675
8.0	79.42	79.82	79.82	.3720
9.0	79.86	80.23	80.23	.3746
10.0	80.26	80.62	80.62	.3763
20.0	83.35	83.56	83.56	.3788

VARIABLE AMBIENT CONDITIONS

FOR CAP = .25, T WB = 60, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = .25, T WB = 70, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

WITH THE VARIOUS AMBIENT TEMPERATURES
THE COSTS ARE -

OPERATING COST = .001 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .004 MILLS/KW-HR

TOTAL SYSTEM COST = .118 MILLS/KW-HR

The MAINTENANCE COST result is a sum of fixed percentages of the specific capital costs, the operating cost, and the condenser system cost. The three percentages are 0.1%, 10% and 1% respectively.

The CONDENSER SYSTEM COST consists of a capital cost (converted to a cost per output basis) and an operating cost, both described in Section 3.2. The condenser system cost is set equal to zero if the condenser is specified. This is true in all the cooling system subroutines. The reason for this is that if an existing condenser is going to be used, its cost should not be part of the optimization process, and also the costs should already be known. When this cost is given (for the "design" condenser case) it represents a total condenser system cost and is not the cost over and above what a specified condenser might cost.

The DIFFERENTIAL FUEL COST is the added cost, due to increased fuel consumption, of operating the plant at a condenser pressure higher than the specified base pressure (input).

The TOTAL SYSTEM COST is the sum of the capital, operating, maintenance, condenser system, and differential fuel costs. This is the cost with which the optimization is performed; the set of variables resulting in the lowest total system cost is considered to be the best.

The river temperatures and plume width were described in Section 3.2 and the printout is self explanatory.

The initial printout for the variable ambient conditions occurs during calculation of the costs for each set of ambient conditions, and are non-fatal error indications. The two messages that occur are that the condenser pressure, PC, is less than the specified (in the input) minimum, PC MIN, or that the discharge temperature, T DIS, exceeds the maximum allowable, T DIS MAX.* The reason for the first type of message is that the trial calculations for the off design (variable ambient conditions) condenser pressure start at the specified minimum condenser pressure for

*This type of message does not occur for the once-through cooling system, but is discussed here for continuity.

each capacity. If the cooling system is able to handle the heat rejected at this first trial point, it means that the actual operating point should be at a lower condenser pressure. However, this point has been specified as the minimum possible pressure, so it is assumed that the plant operates at this pressure and the operating cost is calculated. A large number of such messages may therefore mean that the "design" ambient conditions are too severe compared to the actual variable conditions, or that the minimum allowable condenser pressures have been set too high.

The second type of message, concerning the discharge temperature from an external cooling system, may occur only when the system is used in a topping operation. The message is self explanatory, and may indicate that the "design" ambient conditions are not severe enough relative to the variable conditions. When the situation indicated by the message occurs ($T_{DIS} > T_{DIS\ MAX}$) the program assumes the actual discharge temperature and calculates the operating cost.

The average operating cost and average differential fuel cost for all the variable ambient conditions are calculated and printed out along with a new total system cost. The new modified total system cost is a sum of the original capital, maintenance, and condenser system costs, and the new averaged operating and differential fuel costs.

Section 4
COOLING POND

4.1 General Description

The equations and logic describing the design of a cooling pond are contained in the subroutine SUBPOND. This subroutine "calls" PAF CST for power plant information and COND for condenser specifications. It is possible to have the condenser specified, in which case the cooling pond is sized to match the condenser. If the condenser is not specified, the subroutine "designs" a matched pond and condenser. In both cases, options are available to have the pond used for a topping operation and/or part time use. Pond sizing, in all cases, closely follows the method described in Reference 4.

The subroutine is divided into two sections, a design and an off-design section, similar to the once-through cooling system subroutine.

4.2 Assumptions

Variables and equations for which numerical assumptions have been made in the subroutine are listed below, so that the cards may be changed if different numerical values are desired.

<u>Variable (sequence or line #)</u>	<u>Comment and/or Recommended Values</u>
PMPEF (449)	0.8 - 0.85
WCOFA (452) } WCOFB (453) }	Should be of the form used in Reference 5.
DT2 (490)	Need not correspond to (not used for) specified condenser
PHEAD (521)	
COSMAI (526)	Form of equation and percentages both assumed.

4.3 Basic Equations

The equation for determining the size of the cooling pond necessary for given inlet and outlet water temperatures and ambient temperatures is taken from Reference 4.

$$\text{AREAP} = \frac{24 \times \text{ALPHA} \times \text{FLOW}}{\text{XK} \times 43560} \quad (\text{acres}) \quad (4.1)$$

where FLOW = water flow (lbm/hr)
 XK = exchange coefficient (Btu/day-ft²-°F)

ALPHA is defined by the equation

$$\text{ALPHA} = -\text{LOG} \frac{(\text{T2} - \text{TCALC})}{(\text{T1} - \text{TCALC})} \quad (4.2)$$

where TCALC = equilibrium temperature (°F)
 T1 = inlet water temperature (°F)
 T2 = outlet water temperature (°F)

The capital cost of the pond is simply

$$\text{CAPCOS} = \text{AREAP} \times \text{PRPAGR} \quad (4.3)$$

where PRPAGR = land and construction cost (\$/acre)

4.4 Flow Diagram

The flow diagram for the subroutine SUBPOND is shown in Figures 4.1 and 4.2.

4.5 Results

The results using the data of all four data sets are shown in Tables 4.1 through 4.4 and are described as follows:

Q REJECT and T CONDENSER	-	described in Section 3.4
PUMP POWER	-	total pumping power required exclusive of condenser
H ₂ O EVAP	-	water evaporation rate
COND FLOW	-	condenser water flow (lbm/hr)
T IN	-	temperature at inlet to pond (exit of condenser) (°F)
RANGE	-	ΔT from inlet to exit of pond (°F)
EQUILIBRIUM TEMP	-	described in Section 3.4 (°F)
POND AREA	-	the designed surface area of the pond
Q REJ POND	-	the amount of heat that is transferred from the pond to the atmosphere. (different from total heat rejected only when topping operation)
CAPITAL COST	-	the capital cost of the cooling pond, exclusive of the condenser

The remaining data and costs are the same as those described in Section 3.4.

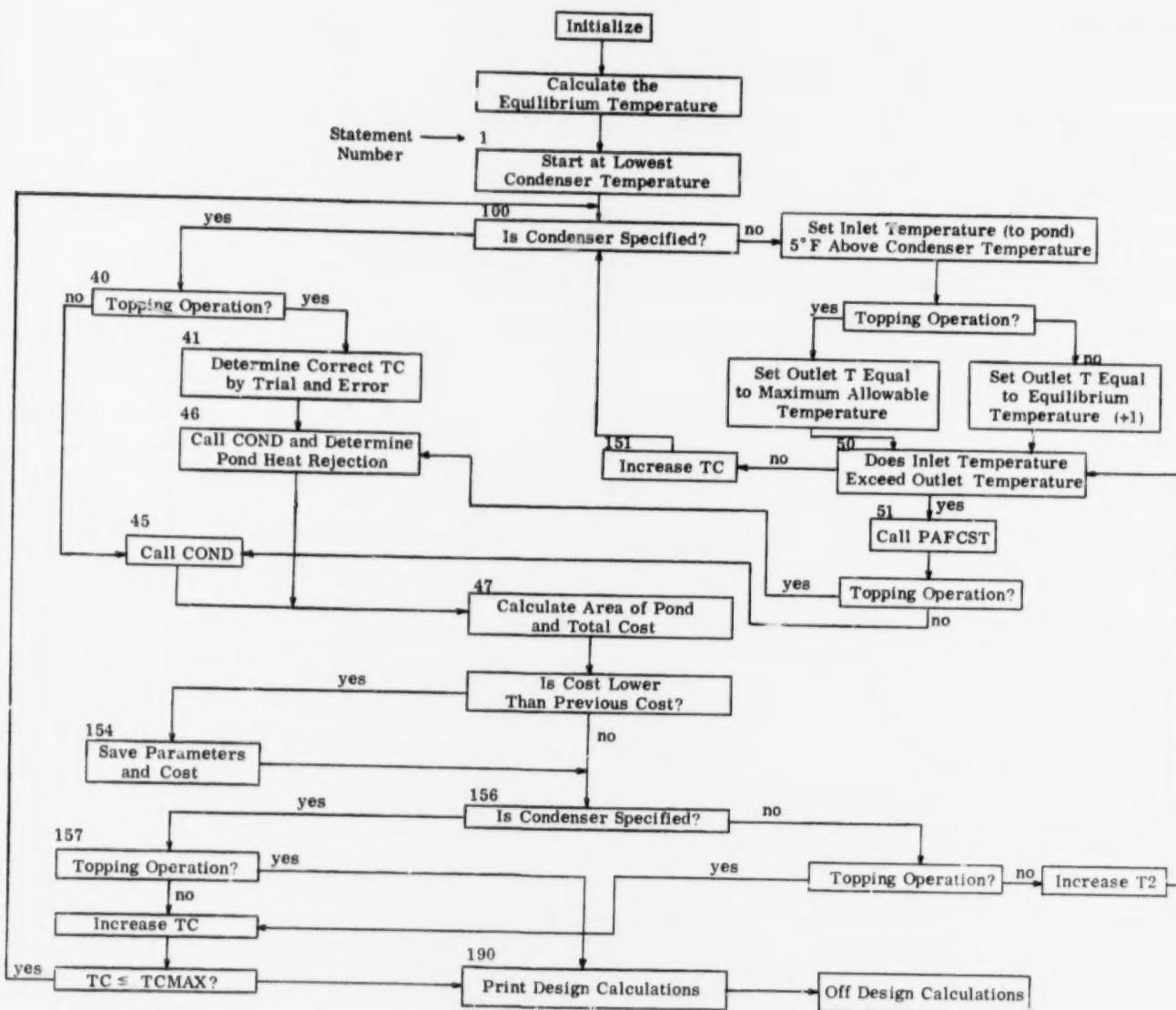


Figure 4.1. Flow Diagram for Design Portion of SUBPOND

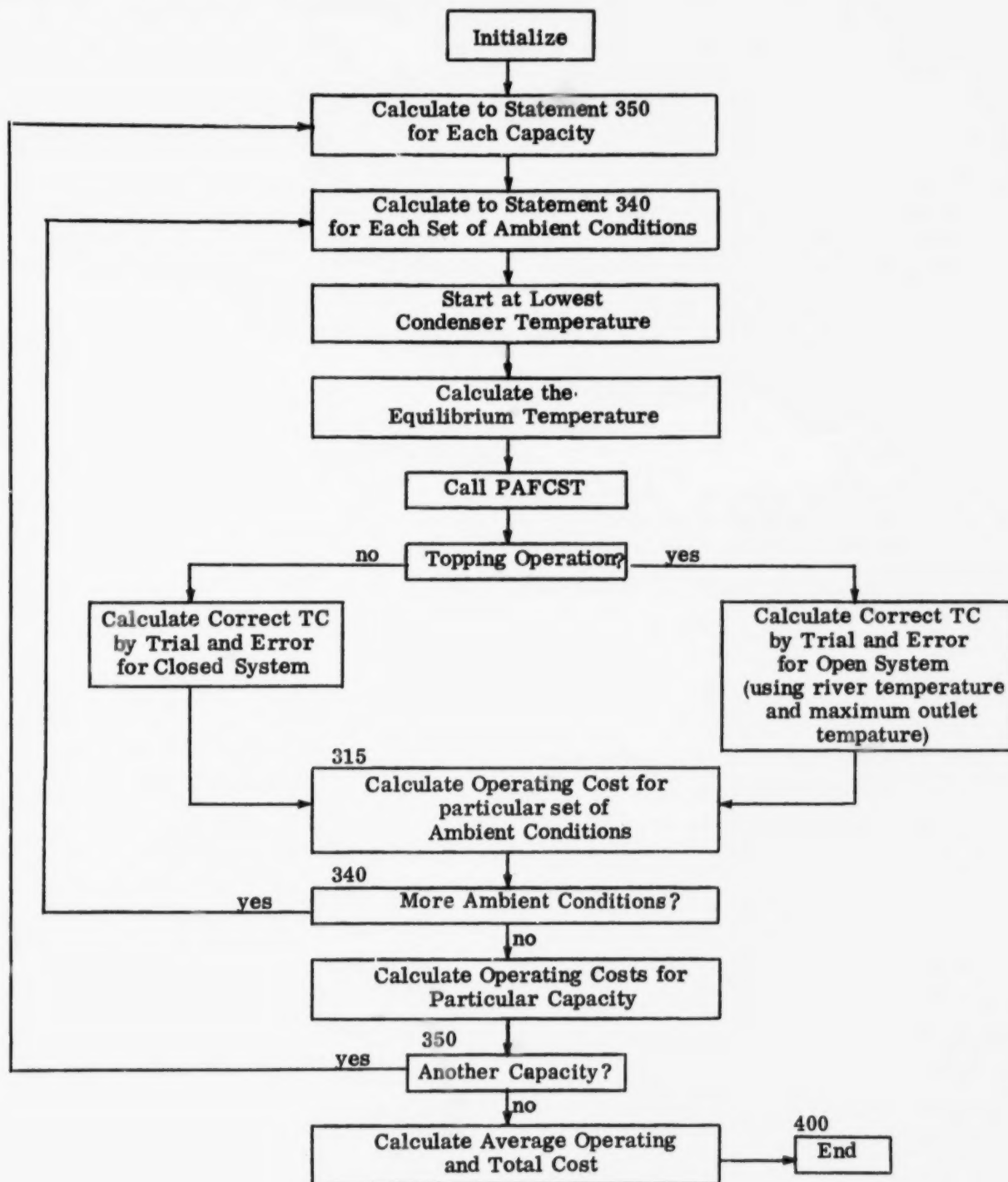


Figure 4.2. Flow Diagram for Off-Design Portion of SUBPOND

Table 4.1
COOLING POND RESULTS USING SUBD1
(SPECIFIED CONDENSER, TOPPING)

----- COOLING POND -----

THE DESIGN VALUES AND COSTS ARE -

Q REJECT = 9.181E 08 BTU/HR AT T CONDENSER = 100
FAN POWER = 0E 00 HP PUMP POWER = 8.047E 02 HP
H2O EVAP = 2.125E 00 CFS (5.199E 05 LR/HR)
H2O BLOWDOWN = 0E 00 CFS (0E 00 LR/HR)
AIR FLOW RATE = 0E 00 LR/HR
COND FLOW = 4.200E 07 T IN = 97 RANGE = 12
EQUILIBRIUM TEMP = 79 POND AREA = 141 ACRES

Q REJ POND = 5.061E 08 BTU/HR

CAPITAL COST = 1.411E 05 DOLLARS
CONDENSER AND PUMP COST = 0E 00 DOLLARS/KW
OPERATING COST = .007 MILLS/KW-HR
MAINTENANCE COST = .001 MILLS/KW-HR
CONDENSER SYSTEM COST = 0 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .000 MILLS/KW-HR

TOTAL SYSTEM COST = .021 MILLS/KW-HR

VARIABLE AMBIENT CONDITIONS

THE POND IS LARGER THAN NECESSARY FOR 1.00 CAPACITY AND AMBIENT NO. 1
COMPUTING COSTS ASSUMING MOST EFFICIENT CONDITION (PC=PCMIN)

THE POND IS LARGER THAN NECESSARY FOR 1.00 CAPACITY AND AMBIENT NO. 2
COMPUTING COSTS ASSUMING MOST EFFICIENT CONDITION (PC=PCMIN)

THE POND IS LARGER THAN NECESSARY FOR .60 CAPACITY AND AMBIENT NO. 1
COMPUTING COSTS ASSUMING MOST EFFICIENT CONDITION (PC=PCMIN)

THE POND IS LARGER THAN NECESSARY FOR .25 CAPACITY AND AMBIENT NO. 1
COMPUTING COSTS ASSUMING MOST EFFICIENT CONDITION (PC=PCMIN)

THE POND IS LARGER THAN NECESSARY FOR .25 CAPACITY AND AMBIENT NO. 2
COMPUTING COSTS ASSUMING MOST EFFICIENT CONDITION (PC=PCMIN)

THE POND IS LARGER THAN NECESSARY FOR .25 CAPACITY AND AMBIENT NO. 3
COMPUTING COSTS ASSUMING MOST EFFICIENT CONDITION (PC=PCMIN)

WITH THE VARIOUS AMBIENT TEMPERATURES
THE COSTS ARE -

OPERATING COST = .007 MILLS/KW-HR
DIFFERENTIAL FUEL COST = -0.000 MILLS/KW-HR

TOTAL SYSTEM COST = .020 MILLS/KW-HR

Table 4.2
COOLING POND RESULTS USING SUBD2
(SPECIFIED CONDENSER, CLOSED SYSTEM)

----- COOLING POND -----

THE DESIGN VALUES AND COSTS ARE -

Q REJECT = 9.351E 08 BTU/HR AT T CONDENSER = 115
FAN POWER = 0E 00 HP PUMP POWER = 8.107E 02 HP
H2O EVAP = 3.438E 00 CFS (8.414E 05 LR/HR)
H2O BLOWDOWN = 0E 00 CFS (0E 00 LR/HR)
AIR FLOW RATE = 0E 00 LR/HR
COND FLOW = 4.200E 07 T IN = 112 RANGE = 22
EQUILIBRIUM TEMP = 79 POND AREA = 142 ACRES

CAPITAL COST = 1.417E 05 DOLLARS
CONDENSER AND PUMP COST = 0E 00 DOLLARS/KW
OPERATING COST = .007 MILLS/KW-HR
MAINTENANCE COST = .001 MILLS/KW-HR
CONDENSER SYSTEM COST = 0 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .007 MILLS/KW-HR

TOTAL SYSTEM COST = .027 MILLS/KW-HR

VARIABLE AMBIENT CONDITIONS

WITH THE VARIOUS AMBIENT TEMPERATURES
THE COSTS ARE -

OPERATING COST = .007 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .005 MILLS/KW-HR

TOTAL SYSTEM COST = .025 MILLS/KW-HR

Table 4.3

COOLING POND RESULTS USING SUBD3
("DESIGN" CONDENSER, TOPPING)

----- COOLING POND -----

THE DESIGN VALUES AND COSTS ARE -

Q REJECT = 9.454E 08 BTU/HR AT T CONDENSER = 120
FAN POWER = 0E 00 HP PUMP POWER = 4.623E 02 HP
H2O EVAP = 2.564E 00 CFS (6.274E 05 LR/HR)
H2O FLOWDOWN = 0E 00 CFS (0E 00 LR/HR)
AIR FLOW RATE = 0E 00 LR/HR
COND FLOW = 2.380E 07 T IN = 115 RANGE = 30
EQUILIBRIUM TEMP = 79 POND AREA = 129 ACRES

Q REJ POND = 7.074E 08 BTU/HR

CAPITAL COST = 6.432E 05 DOLLARS
CONDENSER AND PUMP COST = 5.093E 00 DOLLARS/KW
OPERATING COST = .004 MILLS/KW-HR
MAINTENANCE COST = .005 MILLS/KW-HR
CONDENSER SYSTEM COST = .091 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .010 MILLS/KW-HR

TOTAL SYSTEM COST = .164 MILLS/KW-HR

VARIABLE AMBIENT CONDITIONS

THE POND IS LARGER THAN NECESSARY FOR .25 CAPACITY AND AMBIENT NO. 1
COMPUTING COSTS ASSUMING MOST EFFICIENT CONDITION (PC=PCMIN)

THE POND IS LARGER THAN NECESSARY FOR .25 CAPACITY AND AMBIENT NO. 2
COMPUTING COSTS ASSUMING MOST EFFICIENT CONDITION (PC=PCMIN)

WITH THE VARIOUS AMBIENT TEMPERATURES
THE COSTS ARE -

OPERATING COST = .004 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .004 MILLS/KW-HR

TOTAL SYSTEM COST = .158 MILLS/KW-HR

Table 4.4
COOLING POND RESULTS USING SUBD4
("DESIGN" CONDENSER, CLOSED SYSTEM)

----- COOLING POND -----

THE DESIGN VALUES AND COSTS ARE -

Q REJECT = 9.454E 08 BTU/HR AT T CONDENSER = 120
FAN POWER = 0E 00 HP PUMP POWER = 6.803E 02 HP
H2O EVAP = 3.514E 00 CFS (8.599E 05 LB/HR)
H2O BLOWDOWN = 0E 00 CFS (0E 00 LB/HR)
AIR FLOW RATE = 0E 00 LB/HR
COND FLOW = 3.509E 07 T IN = 115 RANGE = 27
EQUILIBRIUM TEMP = 79 POND AREA = 150 ACRES

CAPITAL COST = 7.487E 05 DOLLARS
CONDENSER AND PUMP COST = 6.277E 00 DOLLARS/KW
OPERATING COST = .006 MILLS/KW-HR
MAINTENANCE COST = .006 MILLS/KW-HR
CONDENSER SYSTEM COST = .114 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .010 MILLS/KW-HR

TOTAL SYSTEM COST = .199 MILLS/KW-HR

VARIABLE AMBIENT CONDITIONS

WITH THE VARIOUS AMBIENT TEMPERATURES
THE COSTS ARE -

OPERATING COST = .006 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .008 MILLS/KW-HR
TOTAL SYSTEM COST = .196 MILLS/KW-HR

Section 5

MECHANICAL DRAFT WET COOLING TOWER

5.1 General Description

The calculations and logic for the design of a mechanical draft cooling system are contained in the subroutine SUBMDW. This subroutine "calls" PAFCST for power plant information and COND for condenser specifications. The condenser may be specified or "designed," the cooling system may be open or closed, and part time or full time use of the cooling system may be specified.

The design method that is used is basically a trial and error procedure in which temperatures are varied over permissible ranges, and the total system cost is calculated for each set of conditions. The set of parameters that represents the lowest total system cost is then chosen.

The subroutine is divided into two sections, a design and an off-design section similar to the once through-cooling system subroutine.

5.2 Assumptions

Variables and equations for which numerical assumptions have been made in the subroutine are listed below, so that the cards may be changed if different numerical values are desired.

<u>Variable (sequence or line #)</u>	<u>Comments and/or Recommended Values</u>
FANEF (668)	0.5 - 0.8
PMPEF (669)	0.8 - 0.85
DT2 (703)	Need not correspond to (for not used) specified condenser
DECKHT (735) } PHT(736) }	Constants must correspond to form of equation - Reference 7
WLOAD (738)	2500.
CONCR (805)	cf Reference 1
CAPCOS (813)	

5.3 Basic Equations

The equations for the size of the cooling tower are based on a calculation of a tower "characteristic," CHAR. Calculation of this characteristic is done with the use of the Tchebycheff (cf Ref. 6) numerical integral approximation, such that

$$\text{CHAR} = \frac{RA}{4} \times [\text{RDH1} + \text{RDH2} + \text{RHD3} + \text{RHD4}] \quad (5.1)$$

where $RA = \text{range} = (T1 - T2) \text{ (}^\circ\text{F)}$, and the RDH's are defined as follows;

RDH1 - inverse of the difference between saturation enthalpy and actual enthalpy, evaluated at $T2 + 0.1 \times (T1 - T2)$ (lbm/Btu)

RDH2 - inverse of the difference between saturation enthalpy and actual enthalpy, evaluated at $T2 + 0.4 \times (T1 - T2)$ (lbm/Btu)

RDH3 - inverse of the difference between saturation enthalpy and actual enthalpy, evaluated at $T1 - 0.4 \times (T1 - T2)$ (lbm/Btu)

RDH4 - inverse of the difference between saturation enthalpy and actual enthalpy, evaluated at $T1 - 0.1 \times (T1 - T2)$ (lbm/Btu)

where $T1 = \text{inlet water temperature (}^\circ\text{F)}$
 $T2 = \text{outlet water temperature (}^\circ\text{F)}$

The packing height in the tower required to give this characteristic is calculated by (Ref. 7)

$$PHT = \frac{DECKHT \times (CHAR - 0.7)}{0.103 \times (WART)^{-0.54}} \quad (5.2)$$

where WART = water to air flow ratio

DECKHT = deck spacing (ft)

The capital cost of the tower is calculated by

$$CAPCOS = 3. \times GPMT \times XK(IK) \times CWB \quad (5.3)$$

where GPMT = total water flow rate (gal/min)

XK(IK) = cooling factor obtained from a curve fit of data of Reference 8, reproduced in Figure 5.1

CWB = wet bulb factor-obtained from Reference 8, reproduced in Figure 5.2

The coefficient, 3, of Equation (5.3) is an average of data from References 8 and 9.

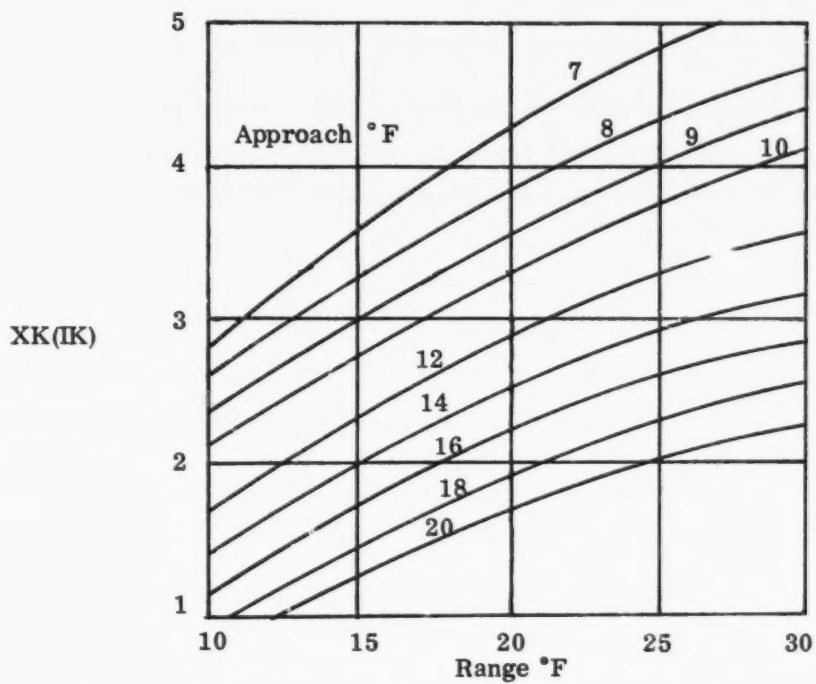


Figure 5.1. Cooling Factor as a Function of Range and Approach (Ref. 8)

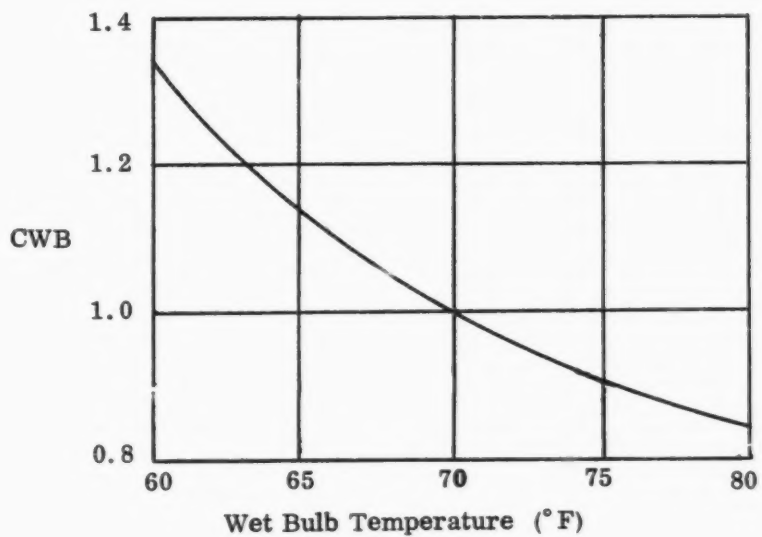


Figure 5.2. Wet Bulb Factor (Ref. 8)

5.4 Flow Diagram

The flow diagram for the design portion of the subroutine SUBMDW is shown in Figure 5.3. A flow diagram for the off-design portion of the program has not been provided since it would be essentially the same as the off design flow diagram for the cooling pond, Figure 4.2.

5.5 Results

The results using the data of all four data sets are shown in Tables 5.1 through 5.4. The description of the results is the same as contained in Sections 3.4 and 4.4 with the exceptions and additions noted below.

- FAN POWER - the total fan power required for the tower
- H2O BLOWDOWN - the required water addition to maintain the specified concentration (cf Ref. 4, pg. 65)
- AIR FLOW RATE - the total air flow rate through the tower
- PRESSURE DROP - the air pressure drop across the tower packing (inches of water)
- APPROACH - the difference between the water outlet temperature from the tower and the wet bulb temperature

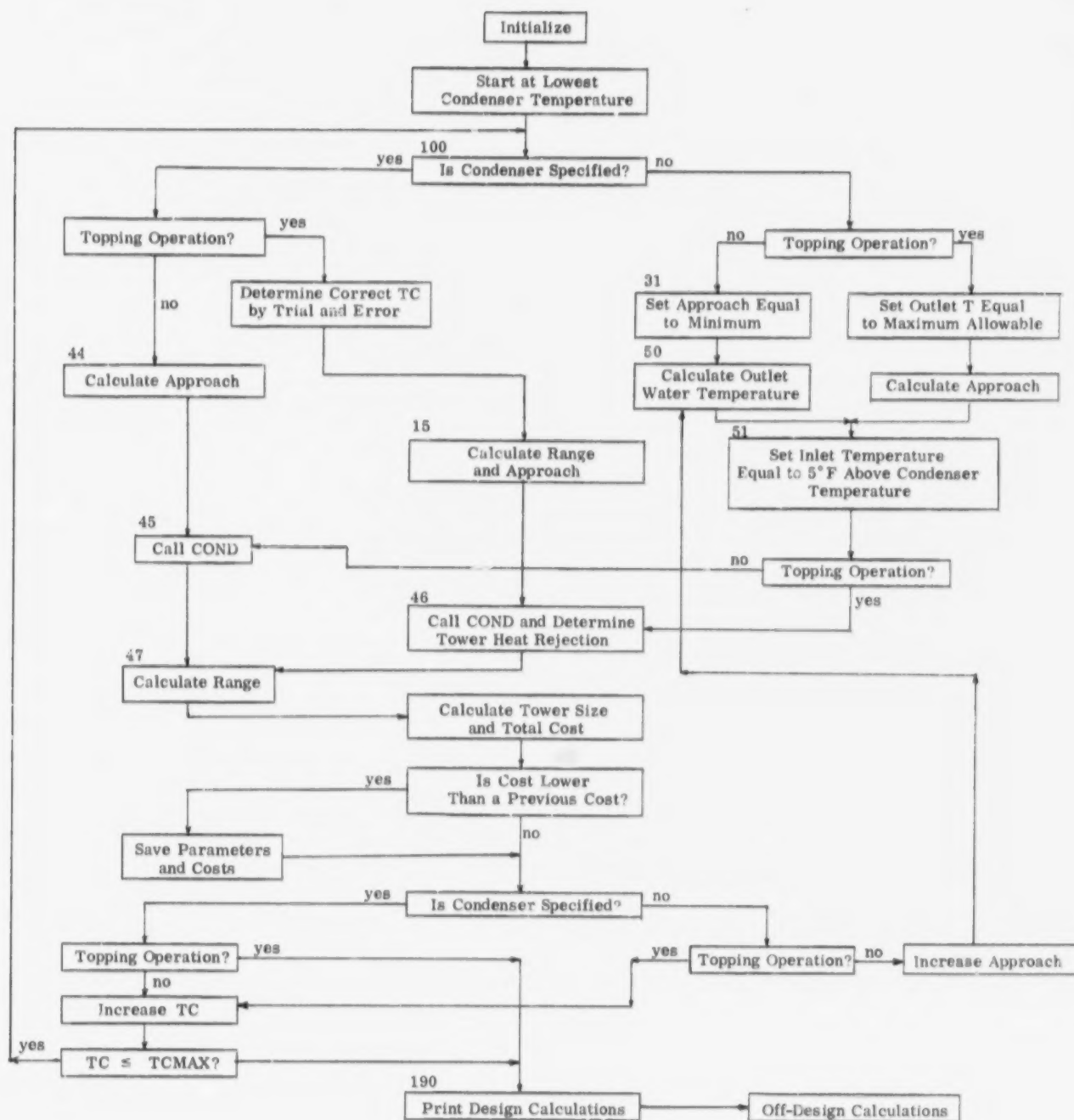


Figure 5.3. Flow Diagram for Design Portion of SUBMDW

Table 5.1

MECHANICAL DRAFT TOWER RESULTS USING SUBD1
(SPECIFIED CONDENSER, TOPPING)

----- MECHANICAL DRAFT WET TOWER -----

THE DESIGN VALUES AND COSTS ARE -

Q REJECT = 9.141E 08 BTU/HR AT T CONDENSER = 100
FAN POWER = 4.770E 02 HP PUMP POWER = 1.068E 03 HP
H2O EVAP = 1.955E 00 CFS (4.784E 05 LB/HR)
H2O RLOWDOWN = 5.176E-01 CFS (1.267E 05 LB/HR)
AIR FLOW RATE = 2.679E 07 LB/HR
PRESSURE DROP = .38 COND FLOW = 4.200E 07
RANGE = 12 APPROACH = 10

Q REJ TOWER = 5.061E 08 BTU/HR

CAPITAL COST = 5.612E 05 DOLLARS
CONDENSER AND PUMP COST = 0E 00 DOLLARS/KW
OPERATING COST = .014 MILLS/KW-HR
MAINTENANCE COST = .004 MILLS/KW-HR
CONDENSER SYSTEM COST = 0 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .000 MILLS/KW-HR

TOTAL SYSTEM COST = .065 MILLS/KW-HR

VARIABLE AMBIENT CONDITIONS

FOR CAP = 1.00, T WB = 60, AND TC = 92
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = 1.00, T WB = 70, AND TC = 92
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = .60, T WB = 60, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = .25, T WB = 60, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = .25, T WB = 70, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = .25, T WB = 70, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

WITH THE VARIOUS AMBIENT TEMPERATURES
THE COSTS ARE -

OPERATING COST = .014 MILLS/KW-HR
DIFFERENTIAL FUEL COST = 0.000 MILLS/KW-HR

TOTAL SYSTEM COST = .064 MILLS/KW-HR

Table 5.2

MECHANICAL DRAFT TOWER RESULTS USING SUBD2
(SPECIFIED CONDENSER, CLOSED SYSTEM)

----- MECHANICAL DRAFT WET TOWER -----

DESIGN VALUES AND COSTS ARE -

Q REJECT = 9.431E 08 BTU/HR AT T CONDENSER = 119
FAN POWER = 2.749E 02 HP PUMP POWER = 9.667E 02 HP
H2O EVAP = 3.527E 00 CFS (8.631E 05 LB/HR)
H2O RLOWDOWN = 9.646E-01 CFS (2.360E 05 LB/HR)
AIR FLOW RATE = 2.208E 07 LB/HR
PRESSURE DROP = .27 COND FLOW = 4.200E 07
RANGE = 22 APPROACH = 19

CAPITAL COST = 2.631E 05 DOLLARS
CONDENSER AND PUMP COST = 0E 00 DOLLARS/KW
OPERATING COST = .011 MILLS/KW-HR
MAINTENANCE COST = .002 MILLS/KW-HR
CONDENSER SYSTEM COST = 0 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .010 MILLS/KW-HR

TOTAL SYSTEM COST = .045 MILLS/KW-HR

VARIABLE AMBIENT CONDITIONS

FOR CAP = 1.00, T WR = 60, AND TC = 92
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = .25, T WR = 70, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = .25, T WR = 70, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

WITH THE VARIOUS AMBIENT TEMPERATURES
THE COSTS ARE -

OPERATING COST = .011 MILLS/KW-HR
DIFFERENTIAL FUEL COST = -0.000 MILLS/KW-HR
TOTAL SYSTEM COST = .035 MILLS/KW-HR

Table 5.3
MECHANICAL DRAFT TOWER RESULTS USING SUBD3
("DESIGN" CONDENSER, TOPPING)

----- MECHANICAL DRAFT WET TOWER -----

THE DESIGN VALUES AND COSTS ARE -

Q REJECT = 9.454E 08 BTU/HR AT T CONDENSER = 120
FAN POWER = 7.221E 02 HP PUMP POWER = 7.148E 02 HP
H2O EVAP = 2.650E 00 CFS (6.485E 05 LB/HR)
H2O BLOWDOWN = 7.235E-01 CFS (1.770E 05 LB/HR)
AIR FLOW RATE = 2.154E 07 LB/HR
PRESSURE DROP = .72 COND FLOW = 2.380E 07
RANGE = 30 APPROACH = 10

Q REJ TOWER = 7.074E 08 BTU/HR

CAPITAL COST = 5.543E 05 DOLLARS
CONDENSER AND PUMP COST = 5.093E 00 DOLLARS/KW
OPERATING COST = .013 MILLS/KW-HR
MAINTENANCE COST = .005 MILLS/KW-HR
CONDENSER SYSTEM COST = .091 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .010 MILLS/KW-HR

TOTAL SYSTEM COST = .166 MILLS/KW-HR

VARIABLE AMBIENT CONDITIONS

FOR CAP = .25, T WB = 60, AND
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

TC = 79

FOR CAP = .25, T WB = 70, AND
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

TC = 79

WITH THE VARIOUS AMBIENT TEMPERATURES
THE COSTS ARE -

OPERATING COST = .013 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .004 MILLS/KW-HR

TOTAL SYSTEM COST = .159 MILLS/KW-HR

Table 5.4

MECHANICAL DRAFT TOWER RESULTS USING SUBD4
("DESIGN" CONDENSER, CLOSED SYSTEM)

----- MECHANICAL DRAFT WET TOWER -----

THE DESIGN VALUES AND COSTS ARE -

Q REJECT = 9.454E 08 BTU/HR AT T CONDENSER = 120
FAN POWER = 3.953E 02 HP PUMP POWER = 9.780E 02 HP
H2O EVAP = 3.536E 00 CFS (8.652E 05 LB/HR)
H2O RLOWDOWN = 9.669E-01 CFS (2.366E 05 LB/HR)
AIR FLOW RATE = 2.459E 07 LB/HR
PRESSURE DROP = .35 COND FLOW = 3.985E 07
RANGE = 24 APPROACH = 16

CAPITAL COST = 5.523E 05 DOLLARS
CONDENSER AND PUMP COST = 6.700E 00 DOLLARS/KW
OPERATING COST = .013 MILLS/KW-HR
MAINTENANCE COST = .005 MILLS/KW-HR
CONDENSER SYSTEM COST = .122 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .010 MILLS/KW-HR

TOTAL SYSTEM COST = .197 MILLS/KW-HR

VARIABLE AMBIENT CONDITIONS

WITH THE VARIOUS AMBIENT TEMPERATURES
THE COSTS ARE -

OPERATING COST = .012 MILLS/KW-HR
DIFFERENTIAL FUEL COST = -0.000 MILLS/KW-HR
TOTAL SYSTEM COST = .186 MILLS/KW-HR

Section 6

NATURAL DRAFT WET COOLING TOWER

6.1 General Description

The logic and calculations for the design of a natural draft cooling tower system are contained in the subroutine SUBNDW. This subroutine obtains power plant information by "calling" PAF CST, and condenser specifications by "calling" COND. The condenser may be specified or designed, the cooling system may be open or closed, and part time or full time use of the coding system may be specified.

The design method is the same as for the mechanical draft system, in that temperatures are varied over permissible ranges and the total system cost is calculated for each set of conditions. The set of conditions resulting in the lowest total cost is then chosen as the design conditions.

The subroutine is divided into a design and an off-design section similar to other cooling system subroutines.

6.2 Assumptions

Variables and equations for which numerical assumptions have been made in the subroutine are listed below, so that the cards may be changed if different numerical values are desired.

<u>Variable (sequence or line#)</u>	<u>Comment and/or Recommended Values</u>
PMPEF (966)	0.8 - 0.85
HDRMAX (968)	1. - 1.75
DT2 (1002)	Need not correspond to (not used for) specified condenser
WLOAD (1014)	Initial value needed
VIN (1046)	2. - 10.
PPK (1055)	Form of equation and constant - Reference 10
PSP (1057)	Form of equation and constants - Reference 16
TPIX (1059)	
CAPCOS (1069)	
CONCR (1070)	cf Reference 1

6.3 Basic Equations

The equations for the size of the cooling tower are based on a calculation of a tower "characteristic," CHAR, and a tower height, THT, necessary to develop the required pressure differential.

The tower characteristic, CHAR, is calculated in the same manner as for the mechanical draft system, Equation (5.1).

The packing height required in the tower to give this characteristic is calculated by (Ref. 10)

$$PHT = \frac{CHAR}{UNC} \quad (6.1)$$

where UNC is the characteristic per foot of packing and is calculated by

$$UNC = 0.1 \times \left(\frac{1}{WART} \right)^{0.73} \quad (6.2)$$

where WART = ratio of water to air flow rates.

The total tower height required is the sum of the sum of the chimney height required for the pressure differential, the packing height, the height of the spray nozzles above the packing, and the air inlet opening height. This is expressed as

$$THT = \frac{TPDP \times VHDI}{DIN - DOUT} \quad (6.3)$$

where TPDP = total pressure drop (air inlet velocity heads)

VHDI = inlet velocity head (lbf/ft²)

DIN, DOUT = inlet and exit air density (lbm/ft³)

The capital cost of the tower is calculated from data on British towers (Ref. 11) modified slightly to reflect United States prices. The resulting equation for the capital is

$$\text{CAPCOS} = 3.4 \times 10^5 \times (\text{HTDIA})^{.17} \quad (6.4)$$

where HTDIA = height of tower times diameter of tower.

6.4 Flow Diagram

The flow diagram for the design portion of the subroutine SUBNDW is the same as that for the mechanical draft system subroutine SUBMDW, Figure 5.3. The off-design flow diagram is essentially the same as the off-design diagram for the cooling pond system, Figure 4.2. Therefore, neither flow diagram is included in this section.

6.5 Results

The results using the data of all four data sets are shown in Tables 6.1 through 6.4. The description of the results is the same as for the preceding cooling systems with the exceptions noted below.

PRESSURE DROP - total air pressure drop through the tower (lbf/ft²)
TOWER HEIGHT - total height of the tower including opening and packing (ft)
TOWER DIAMETER - base diameter of the tower (ft)
TOWER CHARACTERISTIC - the total tower characteristic (Ref. 6)

In the variable ambient conditions error messages,

CHAR - tower characteristic required
THT - tower height required

A fatal error message may occur within the off-design calculations for closed systems when the cooling system cannot reject the required heat at any condenser temperature between the specified limits. A particular case would be if the condenser temperature and ambient temperatures are the same as the "design" conditions, but the power plant is "operating" slightly off design and is less efficient (the heat rate for 100% capacity is slightly higher than for "design").

Table 6.1

NATURAL DRAFT TOWER RESULTS USING SUBD1
(SPECIFIED CONDENSER, TOPPING)

----- NATURAL DRAFT WET TOWER -----

THE DESIGN VALUES AND COSTS ARE -

Q REJECT = 9.191E 08 BTU/HR AT T CONDENSER = 100
FAN POWER = 0E 00 HP PUMP POWER = 1.454E 03 HP
H2O EVAP = 3.546E 00 CFS (8.677E 05 LB/HR)
H2O FLOWDOWN = 9.390E-01 CFS (2.298E 05 LB/HR)
AIR FLOW RATE = 4.859E 07 LB/HR
PRESSURE DROP = 1.2 COND FLOW = 4.200E 07
RANGE = 12 APPROACH = 10
TOWER HEIGHT = 470 TOWER DIAMETER = 315
WATER LOADING = 538 LBM/HR-FT²
TOWER CHARACTERISTIC = 1.38 PACKING HEIGHT = 12.41

Q REJ TOWER = 5.061E 08 BTU/HR

CAPITAL COST = 2.573E 06 DOLLARS
CONDENSER AND PUMP COST = 0E 00 DOLLARS/KW
OPERATING COST = .013 MILLS/KW-HR
MAINTENANCE COST = .014 MILLS/KW-HR
CONDENSER SYSTEM COST = 0 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .000 MILLS/KW-HR

TOTAL SYSTEM COST = .242 MILLS/KW-HR

VARIABLE AMBIENT CONDITIONS

FOR CAP = 1.00, T WB = 60, AND TC = 92
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = 1.00, T WB = 70, AND TC = 92
T DIS EXCEEDS T DIS MAX - CONTINUING

FOR CAP = .80, T WB = 70, AND TC = 85
T DIS EXCEEDS T DIS MAX - CONTINUING

FOR CAP = .80, T WB = 70, AND TC = 90
T DIS EXCEEDS T DIS MAX - CONTINUING

Table 6.1 (Concluded)

FOR CAP = .60, T WB = 60, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = .60, T WB = 70, AND TC = 80
T DIS EXCEEDS T DIS MAX - CONTINUING

FOR CAP = .60, T WB = 70, AND TC = 85
T DIS EXCEEDS T DIS MAX - CONTINUING

FOR CAP = .25, T WB = 60, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = .25, T WB = 70, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = .25, T WB = 70, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

WITH THE VARIOUS AMBIENT TEMPERATURES
THE COSTS ARE -

OPERATING COST = .013 MILLS/KW-HR

DIFFERENTIAL FUEL COST = -0.000 MILLS/KW-HR

TOTAL SYSTEM COST = .241 MILLS/KW-HR

Table 6.2
NATURAL DRAFT TOWER RESULTS USING SUBD2
(SPECIFIED CONDENSER, CLOSED SYSTEM)

----- NATURAL DRAFT WET TOWER -----
THE DESIGN VALUES AND COSTS ARE -

Q REJECT = 9.454E 08 BTU/HR AT T CONDENSER = 120
FAN POWER = 0E 00 HP PUMP POWER = 1.200E 03 HP
H2O EVAP = 3.537E 00 CFS (8.654E 05 LB/HR)
H2O FLOWDOWN = 9.669E-01 CFS (2.366E 05 LB/HR)
AIR FLOW RATE = 2.114E 07 LB/HR
PRESSURE DROP = 1.5 COND FLOW = 4.200E 07
RANGE = 23 APPROACH = 20
TOWER HEIGHT = 235 TOWER DIAMETER = 207
WATER LOADING = 1250 LBM/HR-FT2
TOWER CHARACTERISTIC = .96 PACKING HEIGHT = 15.80

CAPITAL COST = 2.129E 06 DOLLARS
CONDENSER AND PUMP COST = 0E 00 DOLLARS/KW
OPERATING COST = .011 MILLS/KW-HR
MAINTENANCE COST = .012 MILLS/KW-HR
CONDENSER SYSTEM COST = 0 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .010 MILLS/KW-HR

TOTAL SYSTEM COST = .211 MILLS/KW-HR

VARIABLE AMBIENT CONDITIONS

FOR CAP = .25, T WR = 70, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = .25, T WR = 70, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

WITH THE VARIOUS AMBIENT TEMPERATURES
THE COSTS ARE -

OPERATING COST = .011 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .008 MILLS/KW-HR

TOTAL SYSTEM COST = .207 MILLS/KW-HR

Table 6.3

NATURAL DRAFT TOWER RESULTS USING SUBD3
("DESIGN" CONDENSER, TOPPING)

----- NATURAL DRAFT WET TOWER -----

THE DESIGN VALUES AND COSTS ARE -

Q REJECT = 9.454E 08 BTU/HR AT T CONDENSER = 120
FAN POWER = 0E 00 HP PUMP POWER = 8.841E 02 HP
H2O EVAP = 3.542E 00 CFS (8.667E 05 LR/HR)
H2O BLOWDOWN = 9.669E-01 CFS (2.366E 05 LR/HR)
AIR FLOW RATE = 2.879E 07 LR/HR
PRESSURE DROP = 1.2 COND FLOW = 2.380E 07
RANGE = 30 APPROACH = 10
TOWER HEIGHT = 271 TOWER DIAMETER = 182
WATER LOADING = 911 LBM/HR-FT2
TOWER CHARACTERISTIC = 1.78 PACKING HEIGHT = 15.51

Q REJ TOWER = 7.074E 08 BTU/HR

CAPITAL COST = 2.135E 06 DOLLARS
CONDENSER AND PUMP COST = 5.093E 00 DOLLARS/KW
OPERATING COST = .008 MILLS/KW-HR
MAINTENANCE COST = .012 MILLS/KW-HR
CONDENSER SYSTEM COST = .091 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .010 MILLS/KW-HR

TOTAL SYSTEM COST = .300 MILLS/KW-HR

VARIABLE AMBIENT CONDITIONS

FOR CAP = 1.00, T WB = 70, AND TC = 110
T DIS EXCEEDS T DIS MAX - CONTINUING

FOR CAP = .80, T WB = 70, AND TC = 100
T DIS EXCEEDS T DIS MAX - CONTINUING

FOR CAP = .80, T WB = 70, AND TC = 106
T DIS EXCEEDS T DIS MAX - CONTINUING

FOR CAP = .60, T WB = 70, AND TC = 92
T DIS EXCEEDS T DIS MAX - CONTINUING

FOR CAP = .60, T WB = 70, AND TC = 97
T DIS EXCEEDS T DIS MAX - CONTINUING

FOR CAP = .25, T WB = 60, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

Table 6.3 (Concluded)

FOR CAP = .25, T WB = 70, AND TC = 79
T DIS EXCEEDS T DIS MAX - CONTINUING

FOR CAP = .25, T WB = 70, AND TC = 83
T DIS EXCEEDS T DIS MAX - CONTINUING

WITH THE VARIOUS AMBIENT TEMPERATURES
THE COSTS ARE -

OPERATING COST = .008 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .004 MILLS/KW-HR

TOTAL SYSTEM COST = .293 MILLS/KW-HR

Table 6.4
NATURAL DRAFT TOWER RESULTS USING SUBD4
("DESIGN" CONDENSER, CLOSED SYSTEM)

----- NATURAL DRAFT WET TOWER -----
THE DESIGN VALUES AND COSTS ARE -

Q REJECT = 9.454E 08 BTU/HR AT T CONDENSER = 120
FAN POWER = 0E 00 HP PUMP POWER = 1.140E 03 HP
H2O EVAP = 3.546E 00 CFS (8.678E 05 LR/HR)
H2O BLOWDOWN = 9.669E-01 CFS (2.366E 05 LR/HR)
AIR FLOW RATE = 3.042E 07 LB/HR
PRESSURE DROP = 1.4 COND FLOW = 2.980E 07
RANGE = 32 APPROACH = 8
TOWER HEIGHT = 315 TOWER DIAMETER = 215
WATER LOADING = 820 LBM/HR-FT²
TOWER CHARACTERISTIC = 2.17 PACKING HEIGHT = 21.33

CAPITAL COST = 2.253E 06 DOLLARS
CONDENSER AND PUMP COST = 5.759E 00 DOLLARS/KW
OPERATING COST = .011 MILLS/KW-HR
MAINTENANCE COST = .013 MILLS/KW-HR
CONDENSER SYSTEM COST = .104 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .010 MILLS/KW-HR

TOTAL SYSTEM COST = .326 MILLS/KW-HR

VARIABLE AMBIENT CONDITIONS

WITH THE VARIOUS AMBIENT TEMPERATURES
THE COSTS ARE -

OPERATING COST = .010 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .008 MILLS/KW-HR
TOTAL SYSTEM COST = .323 MILLS/KW-HR

REFERENCES

1. Carey, J.H., Ganley, J.T., and Maulbetsch, J.S., "A Survey and Economic Analysis of Alternate Methods for Cooling Condenser Discharge Water in Thermal Power Plants. Task I Report: Survey of Large-Scale Heat Rejection Equipment," Dynatech Report No. 849, July 21, 1969.
2. Fuller, W.D. and Maulbetsch, J.S., "A Survey and Economic Analysis of Alternate Methods for Cooling Condenser Discharge Water in Thermal Power Plants. Task II Report: Survey of Power Plant Operating Characteristics and Design Criteria," Dynatech Report No. 886, May 26, 1970.
3. Severns, W.H. and Fellows, J.R., Air Conditioning and Refrigeration, Wiley & Sons, Inc., N.Y., 1958.
4. FWPCA, Industrial Waste Guide on Thermal Pollution, September 1968.
5. Edinger, J.E. and Geyer, J.C., "Heat Exchange in the Environment," Edison Electric Institute Publication No. 65-902, 1965.
6. Cooling Tower Institute, Cooling Tower Performance Curves, Millican Press, Ft. Worth, Texas, 1967.
7. Fraas, A.P., and Ozisik, M.N., Heat Exchanger Design, John Wiley & Sons, Inc., N.Y., 1965.
8. Lockhart, F.J., Whitesell, J.M., and Catland, A.C., Jr., "Cooling Towers for the Power Industry," American Power Conference, 1955.
9. Converse, A.O., "Thermal Energy Disposal Methods for the Proposed Nuclear Power Plant at Vernon," Submitted to the State of Vermont, November 1967.
10. Lowe, H.J., and D.G. Christie, "Heat Transfer and Pressure Drop Data on Cooling Tower Packings, and Model Studies of the Resistance of Natural Draught Towers to Airflow," Int. Heat Transfer Conf., 1961, Vol. V-A.
11. Kelly, A.G., and Lawless, N.R., "Economic Sizing of Cooling Towers," Combustion Engineering, August 1962.
12. Bauman, H.C., Fundamentals of Cost Engineering in the Chemical Industry, Reinhold Publishing Co., N.Y., 1964.
13. Perry, J.H., Chemical Engineering Handbook, 3rd Edition, McGraw-Hill Book Co., N.Y., 1960.

14. Goodman, W., "The Evaporative Condenser-Theory and Characteristics," Heating, Piping and Air Conditioning, V.10, No. 3, March 1938.
15. Kays, W.M. and London, A.L., Compact Heat Exchangers, McGraw-Hill Book Co., N.Y., 1958.
16. Risch, R.F., "The Design of a Natural Draught Cooling Tower", London, International Heat Transfer Conference, Denver, 1962.

APPENDIX

Glossary of Variable Names

ACFM	Air Flow Rate (ft^3/min)
ACOND	Condenser Area (ft^2)
AFLR	Air Flow Rate (lbm/hr)
AFLR1	AFLR corresponding to TOTCS1
ALDG	Air Loading (mass velocity) ($\text{lbm}/\text{ft}^2\text{-hr}$)
ALDGE	An Equivalent Air Mass Flow Rate ($\text{lbm}/\text{hr-ft}^2$)
ALPACT	The Actual ALPHA
ALPHA	Exponent for Exponential Temperature Decay
ALPHA1	Exponent for Exponential Temperature Decay
AMBDFC (I)	Differential Fuel Cost for Operation at CAP (I) (mills/kwhr)
AMBOPC (I)	Operating Cost at CAP(I) (mills/kwhr)
AMBRH (J)	Off Design Relative Humidities ($\%/100$)
AMRAD	Off Design Absorbed Radiation ($\text{Btu}/\text{ft}^2\text{-day}$)
AMWIND	Off Design Wind Velocity (mph)
ANFCR	Annual Fixed Charge Rate ($\%/100$)
APPR	Approach - temperature difference between outlet water and wet bulb ($^{\circ}\text{F}$)
APPR1	APPR corresponding to TOTCS1
APSAT	Water Vapor Partial Pressure (psi)
AREAC	Condenser Area for Specified Condenser (ft^2)
AREAP	Cooling Pond Area (acre)
AREAP1	AREAP corresponding to TOTCS1
AVDFCS	Average Off Design Differential Fuel Cost (mills/kwhr)
AVOPCS	Average Off Design Operating Cost (mills/kwhr)
AVTCST	Average Off Design Total Cost (mills/kwhr)
BETA	The derivative of the saturation pressure with respect to temperature, evaluated at the equilibrium temperature ($\text{psi}/^{\circ}\text{F}$)
BOWRAT	Bowen Ratio-Ratio of Conduction to Evaporation Heat Transfer
BSA	Base Area of Tower (ft^2)
CAIR	Heat Capacity Rate ($\text{Btu}/\text{hr}^{\circ}\text{F}$)
CAP(I)	Plant Capacity ($\%/100$)
CAPCOS	Capital Cost (\$)

CAPCS1	CAPCOS corresponding to TOTCS1
CAPFAC	Average Power Plant Capacity Factor ($\%$ /100)
CCPKW	Plant Capital Cost (\$/kw)
CHAR	Tower Characteristic
CHAR1	CHAR corresponding to TOTCS1
CHEAD	Friction Pressure Drop in the Condenser (water side)
CKWHRS	Total Power Output per year during which the cooling system is used (kwhr/yr)
CO1	Total Enthalpy Rise of Air Through Tower (Btu/lbm)
COLPCT(I)	Percent of Operating Time, TOTLD(I), that cooling system is used ($\%$ /100)
CONCR	Ratio of Circulation Water to Raw-Water Minerals Concentration
CONCST	Condenser Cost (\$)
COSMA1	COSMA1 corresponding to TOTCS1
COSMAI	Maintenance Cost (mills/kwhr)
COSPK1	COSPKW corresponding to TOTCS1
COSPKW	Specific Capital Cost (\$/kw)
CWB	Wet Bulb Factor
DECKHT	Deck Spacing (ft)
DELFI	DELFC corresponding to TOTCS1
DELFC	Differential Fuel Cost (mills/kwhr)
DELHR	Change in Heat Rate (Btu/kwhr)
DELHS	Change in Saturation Enthalpy (Btu/lbm)
DELP	Packing Pressure Drop (inches of water)
DEPTH	Condenser Depth (ft)
DFCOD	Off Design Differential Fuel Cost (mills/kwhr)
DH	Net Heat Transfer Rate from water to air - will be zero when the equilibrium temperature is substituted into its defining equation (Btu/ft ² -day)
DHM, DHP	The Heat Transfer Rate from water to air when the water is 1° F below and above the equilibrium temperature (assumed or actual) (Btu/ft ² -day)
DHPRIM	The Derivative of DH with Respect to Temperature (Btu/day ft ² -° F)
DIA	Tower Diameter (at base) (ft)

DIA1	DIA corresponding to TOTCS1
DIN	Inlet Air Density (lbm/ft ³)
DOUT	Exit Air Density (lbm/ft ³)
DP1	DELP corresponding to TOTCS1
DT1	Condenser Temperature Difference = TC - T2 (° F)
DT2	Condenser Temperature Difference (approach) = TC - T1 (° F)
DTLGM	Log Mean Temperature Difference (° F)
DTRIV	Change in total "mixed" river temperature between upstream and just downstream of condenser (° F)
ECOF	Evaporation Coefficient (Btu/ft ² day mm Hg)
FANEF	Fan Efficiency (%/100)
FCFS	Condenser Flow (ft ³ /sec)
FLOW	Condenser flow (lbm/hr)
FLOW1	FLOW corresponding to TOTCS1
FUCST	Fuel Cost (¢/million Btu)
FUDGE	An Intermediate Cost Factor
GPM	Condenser Flow Rate (gal/min)
GPM1	GPM corresponding to TOTCS1
GPMT	Total Flow Rate (gal/min)
H(T)	Saturation Enthalpy at Temperature T (Btu/lbm)
H1	Saturation Enthalpy corresponding to the Wet Bulb Temperature (Btu/lbm)
H2	Saturation Enthalpy corresponding to TAXT (except SUBEVAP) -- SUBEVAP only - Exit Air Enthalpy (Btu/lbm)
HDR	Ratio of Tower Height to Diameter
HDR1	HOVD Corresponding to TOTCS1
HDRMAX	Specified Maximum HOVD
NEATR	Net heat rate (Btu/kwhr)
HOUT	Saturation Enthalpy corresponding to Outlet Air Temperature (Btu/lbm)
HPF1	HPFAN corresponding to TOTCS1
HPFAN	Fan Power (hp)
HPP1	HPPMP corresponding to TOTCS1
HPPMP	Pumping Power (hp)

HR(I, J)	Net Heat Rate Corresponding to HRP(I, J) (Btu/kwhr)
HRBASE	Base net heat rate corresponding to PCBASE (Btu/kwhr)
HRCOF2(I), HRCOF1(I) HRCOF ϕ (I)	Quadratic Heat Rate Coefficients such that HEAT RATE = HRCOF2(I) x (TC) ² + HRCOF1(I) x (TC) + HRCOF ϕ
HRP (I, J)	Condenser Pressure for each Heat Rate Point. THR(I, J) at each CAP(J) (in. Hg.)
HTDIA	Tower Height times Tower Diameter (ft ²)
HWB1	H1 corresponding to TOTCS1
IREAD	Program Read Control Number
ISUB	Program Subroutine Control Number
IRITE	Program Print Out Control Number
IWL	Number of Iterations on WLOAD
NCAPS	Number of Plant Capacities (exclusive of "design" capacity)
NCAPS1	Subscript meaning "Design" Value
NH2O	Type of Cooling Water Used (-1= seawater, 0= untreated fresh water, + 1= treated fresh water)
NHRPTS (I)	Number of Heat Rates Input at each CAP(I)
NSPCON	Whether or not Condenser is Specified (0= nc, 1= yes)
NSUBS(I)	Subroutine Control Flags
NSYSOP	Type of Cooling System Operation (0= closed cycle, 2= topping)
NTAMB	Number of Ambient Temperatures
NTCOD	An Index of the Condenser Temperature has been Incremented
OPCOD	Off Design Operating Cost (mills/kwhr)
OPCOS	Operating Cost (mills/kwhr)
OPCS1	OPCOS corresponding to TOTCS1
OPHT	Tower Inlet Air Opening Height (ft)
OPHT1	OPHT corresponding to TOTCS1
P(T)	Saturation Pressure a T (psia)
PBAR	Atmospheric Pressure (= 14.696 psi)

PCBASE	Base Condenser Pressure (in. Hg.)
PCMAX(I)	Maximum Condenser Pressure for CAP (I) (in. Hg.)
PCMIN(I)	Minimum Condenser Pressure for CAP (I) (in. Hg.)
PCTAMB (I, J)	Percent of Cooling System Use Time, (COLPCT(J) x TOTLD(J)), at each CAP(I) that the system operates at the specified ambient temperatures (TAMDB(J), TAMWB(J)) (%/100)
PHEAD	Frictional Pumping Head (ft.)
PHT	Packing Height (ft)
PKWA	Packing Pressure drop with zero water flow (velocity heads/ft)
PKWB	Slope of packing pressure drop versus water loading curve (hr ft velocity heads/lbm)
PLAC	Cost of Condenser Cooling Water Ducting (\$/kw)
PLAC1	PLAC corresponding to TOTCS1
PLANA	Tower Plan Area (ft ²)
PLANAI	PLANA corresponding to TOTCS1
PLUMEW	Plume Width (ft)
PLUMT	Plume Temperature (° F)
PMPCST	Pumping Cost (mills/kwhr)
PMPEF	Pump Efficiency (%/100)
PPK	Pressure Drop Across Packing (inlet velocity heads)
PPK1	PPK corresponding to TOTCS1
PRPAGR	Cost of Land and Pond Construction (\$/acre)
PSIZE	Rated Plant Output (MW)
PSP	Air Pressure Drop Across Water Spray (inlet velocity heads)
PV	Partial Pressure of Water Vapor (psia)
PWCST	Power cost (for auxiliaries) (mills/kwhr)
QCON	Condenser Water Flow (ft ³ /sec)
QLAT	Latent (evaporation) Heat Transfer (Btu/hr)
QREJ	Heat Rejected by Power Plant (Btu/hr)

QREJT	Heat Rejected by Cooling System (Btu/hr)
QRJ1	QREJ corresponding to TOTCS1
QRJT1	QREJT corresponding to TOTCS1
RA	Condenser or cooling System Range ($^{\circ}$ F)
RA1	RA corresponding to TOTCS1
RAD	Absorbed Radiation (Btu/ft ² day)
RDH1	Inverse of the difference between saturation enthalpy and actual enthalpy, evaluated at $T2 + 0.1 (T1 - T2)$ (lbm/Btu)
RDH2	Inverse of the difference between saturation enthalpy and actual enthalpy, evaluated at $T2 + 0.4 (T1 - T2)$ (lbm/Btu)
RDH3	Inverse of the difference between saturation enthalpy and actual enthalpy, evaluated at $T1 - 0.4 (T1 - T2)$ (lbm/Btu)
RDH4	Inverse of the difference between saturation enthalpy and actual enthalpy, evaluated at $T1 - 0.1 (T1 - T2)$ (lbm/Btu)
SPFLOW	Condenser Water Flow Rate for Specified Condenser (lbm/hr)
SPHT	Distance of Spray nozzles above packing (ft.)
SYS1	SYSCST corresponding to TOTCS1
SYSCST	Condenser System Cost (mills/kwhr)
T1	Temperature of Water out of Condenser (into cooling system) ($^{\circ}$ F)
T11	T1 corresponding to TOTCS1
T2	Temperature of Water into Condenser (from cooling system) ($^{\circ}$ F)
T21	T2 corresponding to TOTCS1
TA	Air Temperature ($^{\circ}$ F)
TAMDB(J)	Off Design Dry Bulb Temperature ($^{\circ}$ F)
TAMRV(J)	Off Design River or Estuary Temperature ($^{\circ}$ F)
TAMWB(J)	Off Design Wet Bulb Temperature ($^{\circ}$ F)

TAVH2O	Available Water Temperature ($^{\circ}$ F)
TAXT	Average of Inlet and Outlet Water Temperatures ($^{\circ}$ F)
TAXT1	TAXT corresponding to TOTCS1
TC	Condenser Temperature ($^{\circ}$ F)
TC1	TC corresponding to TOTCS1
TCALC	Equilibrium Temperature ($^{\circ}$ F)
TCALC1	TCALC corresponding to TOTCS1
TCBASE	Base Condenser Temperature ($^{\circ}$ F)
TCMAX(I)	Maximum Condenser Pressure at CAP(I) ($^{\circ}$ F)
TCMIN(I)	Minimum Condenser Temperature at CAP(I) ($^{\circ}$ F)
TDB	Design Dry Bulb Temperature ($^{\circ}$ F)
TDFMIL	Total Differential Fuel Cost for Each Capacity (mills)
TDISMX	Maximum Water Discharge Temperature ($^{\circ}$ F)
TG	An Initial Guess at the Equilibrium Temperature ($^{\circ}$ F)
THR(I, J)	Condenser Saturation Temperature corresponding to HRP(I, J) ($^{\circ}$ F)
THT	Total Tower height (ft)
THT1	THT corresponding to TOTCS1
TKWHRS	Total Power Output per Year (kwhr/yr)
TNEW	A New Guess at the Equilibrium Temperature ($^{\circ}$ F)
TOPMIL	Total Operating Cost for each Capacity (mills)
TOTCOS	Total System Cost (mills/kwhr)
TOTCS1	The Minimum Total System Cost calculated up to that point in the Program (mills/kwhr)
TOTHP	Total Auxiliary Power Required for Cooling System (hp)
TOTLD(I)	Hours per year Operating at each corresponding Capacity CAP(I) (hrs/yr)
TOUTS	Saturation Temperature of Outlet Air ($^{\circ}$ F)
TPDP	Total Pressure Drop (inlet velocity heads)
TPDP1	TPDP corresponding to TOTCS1
TPIX	Inlet and exit turning losses plus friction loss (inlet velocity heads)

TURBHR(I, J)	Net Heat Rate corresponding to HRP(I, J) for each CAP(I) (Btu/kwhr)
TWAV	Average Water Temperature ($^{\circ}$ F)
TWB	Design Wet Bulb Temperature ($^{\circ}$ F)
TWREAL	River Temperature XI Downstream from Plant if no heat were added at plant ($^{\circ}$ F)
TXDIST	"Mixed" river temperature XI Downstream from Plant ($^{\circ}$ F)
TZERO	"Mixed" river temperature just downstream of condenser ($^{\circ}$ F)
UA	Heat Transfer Coefficient times Area (Btu/hr- $^{\circ}$ F)
UA1	UA corresponding to TOTCS1
UALL	Overall Heat Transfer Coefficient (Btu/hr-ft ² - $^{\circ}$ F)
UNC	Characteristic per foot of packing
UOVALL	Overall Heat Transfer Coefficient for Specified Condenser (Btu/hr-ft ² - $^{\circ}$ F)
USEFAC	Average Cooling Use Factor (%/100)
VELRIV	River Velocity (ft/day)
VHDI	Inlet Velocity Head (lbf/ft ²)
VIN	Air Inlet Velocity (ft/sec)
WACT	Specific Humidity
WART	Ratio of Water Flow to Air Flow
WART1	WART corresponding to TOTCS1
WBDWN	Water Flow Needed for Blowdown (lbm/hr)
WBDWN1	WBDWN corresponding to TOTCS1
WCOFA, WCOFB	Coefficients such that ECOF = WCOFA + WCOFB x WIND
WEVAP	Water Evaporation Rate (lbm/hr)
WEVAP1	WEVAP corresponding to TOTCS1
WIDTH	Width of River or Estuary (ft)
WIND	Wind Speed (mph)
WLMTD	Log Mean Temperature of Cooling Pond ($^{\circ}$ F)
WLOAD	Water Loading (lbm/hr/ft ²)
WLOAD1	WLOAD corresponding to TOTCS1
WNEED	Total Makeup Water Required (lbm/hr)

WNEED1

XI

XK

XK (IK)

XK1

WNEED corresponding to TOTCS1

Distance Downstream from Plant (mi)

Energy Exchange Coefficient (Btu/day ft-° F)

Cooling Factor defined in Figure 5.1

XK(IK) corresponding to TOTCS1

PROGRAM LISTINGS

	<u>Page</u>
Main Program	A-11
Subroutine SUBPOLU	A-15
Subroutine SUBPOND	A-19
Subroutine SUBMDW	A-23
Subroutine SUBNDW	A-28
Subroutine PAFCST	A-33
Subroutine COND	A-34
Subroutine PRTDS1	A-35
Subroutine PRTDS2	A-36
Subroutine PRTOD	A-37
Function H(I)	A-38
Function P(T)	A-39
Data SUBD1	A-40
Data SUBD2	A-41
Data SUBD3	A-42
Data SUBD4	A-43

PROGRAM MAINFWP	00001
COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,CAP(6),TOTLD(5),	00002
X COLPCT(5),TCMIN(6),PCMIN(6),TCMAX(6),PCMAX(6),	00003
X HRCOF2(6),HRCOF1(6),HRCFO(6),TDB,TWB,RH,TAVH2C,TCBASE,	00004
X NTAMB,AMRDFC(5),AMRQPC(5),TAMDB(5),TAMWB(5),AMBRH(5),	00005
X TAMRV(5),PCTAMB(5,5),NSYSCP,TDISMX,NSPCON,UCVALL,AREAC,SPFLOW,	00006
X NH2C,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHR,IRITE,IREAD,	00007
* AMWIND(5),AMRAD(5),WIND,RAD	00008
DIMENSION NHRPTS(6),HRP(6,6),THR(6,6),TURBHR(6,6),	00009
X HR(6,6),NSUBS(5)	00010
IRITE=31	00011
IREAD=30	00012
200 FORMAT(5F10.0,I10)	00013
201 FORMAT(6F10.0,I2)	00014
202 FORMAT(6F10.0,I2)	00015
203 FORMAT(7I10)	00016
204 FORMAT(6F10.0,2I10)	00017
205 FORMAT(F10.0,2I10,4F10.0)	00018
READ(IREAD,200)PSIZE,CCPKW,ANFCR,FUCST,PRPAGR,NCAPS	00019
NCAPS1=NCAPS+1	00020
READ(IREAD,201)(CAP(I),I=1,5)	00021
READ(IREAD,202)(TOTLD(I),I=1,5)	00022
READ(IREAD,201)(COLPCT(I),I=1,5)	00023
READ(IREAD,203)(NHRPTS(I),I=1,6)	00024
READ(IREAD,201)(PCMIN(I),I=1,6)	00025
READ(IREAD,201)(PCMAX(I),I=1,6)	00026
NNCAP=NCAPS	00027
IF(NHRPTS(NCAPS1).GT.0)NNCAP=NNCAP+1	00028
DO 210 I=1,NNCAP	00029
READ(IREAD,201)(HRP(I,J),J=1,6)	00030
210 READ(IREAD,202)(TURBHR(I,J),J=1,6)	00031
C	00032
C	00033
READ(IREAD,204)TDB,TWB,TAVH2C,PCBASE,WIND,RAD,NH2C,NTAMB	00034
C	00035
READ(IREAD,202)(TAMDB(I),I=1,NTAMB)	00036
READ(IREAD,202)(TAMWB(I),I=1,NTAMB)	00037
READ(IREAD,202)(TAMRV(I),I=1,NTAMB)	00038
READ(IREAD,202)(AMWIND(I),I=1,NTAMB)	00039
READ(IREAD,202)(AMRAD(I),I=1,NTAMB)	00040
C	00041
DO 216 I=1,NCAPS	00042
216 READ(IREAD,201)(PCTAMB(I,J),J=1,NTAMB)	00043
C	00044
READ(IREAD,205)WIDTH,NSYSCP,NSPCON,TDISMX,UCVALL,AREAC,SPFLOW	00045
READ(IREAD,203)(NSUBS(I),I=1,5)	00046
C	00047
C	00048
LOAD DURATION HOURS CHECK - TO STATEMENT 246	00049
TOTDUR=0.0	00050
DO 243 I=1,NCAPS	00051
TOTAM=0.0	00052
C	00053
PERCENT AMBIENT TIME CHECK - TO STATEMENT 242	00054
DO 238 J=1,NTAMB	00055
238 TOTAM=TOTAM+PCTAMB(I,J)	00056
IF(TOTAM.EQ.1.)GO TO 242	00057
WRITE(IRITE,239)I	00058
C	00059
CALC OF RELATIVE HUMIDITY - RH AND AMBRH	00060
239 FORMAT(10TCT PCT AMBIENT HRS NOT = 1.0 FOR CAP NO*,I2)	00061
GO TO 500	00062
242 CONTINUE	
TOTDUR=TOTDUR+TOTLD(I)	
243 CONTINUE	

	IF (TOTDUR .EQ. 8760.) GO TO 246	00063
	WRITE(IRITE,244)	00064
244	FORMAT(# TOT LD HRS NOT = 8760 #)	00065
	GO TO 500	00066
246	CONTINUE	00067
C		00068
	PBAR=14.696	00069
	PV=P(TWB)-(((PBAR-P(TWR))*(TDB-TWB))/(2*NO.-1.3*TWB))	00070
	RH=P/P(TDB)	00071
	DO 20 I=1,NTAMB	00072
20	AMBRH(I)=(P(TAMB(I))-(((PBAR-P(TAMB(I)))*	00073
	X (TAMDR(I)-TAMB(I)))/(2831.-1.43*TAMB(I)))/P(TAMDR(I))	00074
C		00075
C	QUADRATIC CURVE FIT OF HEAT RATES (TO STATEMENT	00076
	NNCAP=NCAPS	00077
	CAP(NCAPS1)=1.	00078
	IF(NHRPTS(NCAPS1) .GT. 0) NNCAP=NNCAP+1	00079
	DO 9 I=1,NNCAP	00080
	IF(NHRPTS(I) .GT. 2) GO TO 7	00081
	WRITE(IRITE,6) I	00082
6	FORMAT(# LESS THAN 3 HEAT RATES FOR CAP NO #,I2)	00083
	GO TO 500	00084
7	X1=0.5X2=0.5X3=0.5X4=0.5XY=0.5X2Y=0.5Y1=0.	00085
	M2=NHRPTS(I)	00086
	DO 8 J=1,M2	00087
C		00088
	HR(I,J)=TURBHR(I,J)	00089
C		00090
C	CALC OF TSAT FROM PRESS. (IN. HG)	00091
	BLOG=ALOG(HRP(I,J))	00092
	THR(I,J)=79.035793+30.462409*BLOG+1.9740416*	00093
	X (BLOG)**2+0.13124035*(BLOG)**3	00094
	X1=THR(I,J)*X1	00095
	X2=(THR(I,J)**2)*X2	00096
	Y1=HP(I,J)*Y1	00097
	X3=(THR(I,J)**3)*X3	00098
	X4=(THR(I,J)**4)*X4	00099
	XY=XY+THR(I,J)*HP(I,J)	00100
	X2Y=X2Y+(THR(I,J)**2)*HR(I,J)	00101
	R=NHRPTS(I)	00102
	DEN=X4*(R*X2-X1**2)-X3*(B*X3-X2*X1)+X2*(X3*X1-X2**2)	00103
	ANUM=X2Y*(B*X2-X1**2)-X3*(B*XY-X1*Y1)+X2*(XY*X1-Y2*Y1)	00104
	RNUM=X4*(B*XY-X1*Y1)-X2Y*(B*X3-X2*X1)+X2*(X3*Y1-XY*X2)	00105
	CNUM=X4*(X2*Y1-XY*X1)-X3*(X3*Y1-XY*X2)+X2Y*(X3*X1-X2**2)	00106
	HRCOF2(I)=ANUM/DEN	00107
	HRCOF1(I)=BNUM/DEN	00108
	HRCOF0(I)=CNUM/DEN	00109
9	CONTINUE	00110
C		00111
C	MAKING DESIGN HR = 100PCT CAPACITY HR (IF NOT SPECIFIED)	00112
	IF(NHRPTS(NCAPS1) .GT. 0) GO TO 45	00113
	DO 40 I=1,NCAPS	00114
	IF(CAP(I) .EQ. 1.) GO TO 42	00115
40	CONTINUE	00116
	WRITE(IRITE,41)	00117
41	FORMAT(# NO 100 PCT CAPACITY OR DESIGN HR#)	00118
	GO TO 500	00119
42	HRCOF2(NCAPS1)=HRCOF2(I)	00120
	HRCOF1(NCAPS1)=HRCOF1(I)	00121
	HRCOF0(NCAPS1)=HRCOF0(I)	00122
	PCMIN(NCAPS1)=PCMIN(I)	00123
	PCMAX(NCAPS1)=PCMAX(I)	00124

C	45	CONTINUE	00125
	DO 11	I=1,NCAPS1	00126
		ALCG=ALCG(PCMIN(I))	00127
		TCHIN(I)=79.035793+30.462409*ALCG+1.9740416*	00128
	X (ALCG)**2+0.13124035*(ALCG)**3		00129
		BLCG=ALCG(PCMAX(I))	00130
	11	TCHMAX(I)=79.035793+30.462409*ALCG+1.9740416*	00131
	X (ALCG)**2+0.13124035*(ALCG)**3		00132
		ALCG=ALCG(PCBASE)	00133
		TCHASE=79.035793+30.462409*ALCG+1.9740416*	00134
	X (ALCG)**2+0.13124035*(ALCG)**3		00135
C			00136
C		CALC OF AVG CAPACITY FACTOR AND COOLING USE FACTOR	00137
		TKWHR=0.0	00138
		CKWHR=0.0	00139
	DO 47	I=1,NCAPS	00140
		TKWHR=TKWHR+(CAP(I)*TOTLD(I))	00141
	47	CKWHR=CKWHR+(CAP(I)*TOTLD(I)*COLPCT(I))	00142
		CAPFAC=TKWHR/8760.	00143
		USEFAC=CKWHR/TKWHR	00144
C			00145
C			00146
	DO 60	ISUB=1,5	00147
		IF(NSURS(ISUB).EQ.0)GO TO 60	00148
		GO TO (50,70,72,74,76)ISUB	00149
	50	WRITE(IRITE,350)PSIZE,CCPKW,ANFCR,FUCST,PRPAGR	00150
	350	FORMAT(141,10X,-----PRINTOUT OF INPUT DATA-----	00151
	X	/1H04X,PSIZE CAP \$ ANFCR FUEL \$ PRPAGR\$ /.	00152
		X5X,F5.0,F9.0,F8.2,F9.0,F10.0//)	00153
C			00154
		WRITE(IRITE,360)(CAP(I),I=1,NCAPS)	00155
		WRITE(IRITE,361)(TOTLD(I),I=1,NCAPS)	00156
		WRITE(IRITE,362)(COLPCT(I),I=1,NCAPS)	00157
		WRITE(IRITE,363)(PCMIN(I),I=1,NCAPS1)	00158
		WRITE(IRITE,364)(TCHIN(I),I=1,NCAPS1)	00159
		WRITE(IRITE,365)(PCMAX(I),I=1,NCAPS1)	00160
		WRITE(IRITE,366)(TCHMAX(I),I=1,NCAPS1)	00161
	360	FORMAT(5X,#CAPACITIES AND CORRESPONDING DATA#:/, 7X, # (EXTRA V	00162
		VALUES ARE DESIGN DATA)#:/, 3X,#CAPACITY - #,5F7.2)	00163
	361	FORMAT(# HRS/YEAR - #,5F7.0)	00164
	362	FORMAT(# PCT COOLING - #,5F7.2)	00165
	363	FORMAT(# MIN P COND - #,6F7.2)	00166
	364	FORMAT(# MIN T COND - #,6F7.2)	00167
	365	FORMAT(# MAX P COND - #,6F7.2)	00168
	366	FORMAT(# MAX T COND - #,6F7.2)	00169
C			00170
		WRITE(IRITE,370)CAPFAC,USEFAC	00171
	370	FORMAT(5X,#CAPACITY FACTOR =#,F5.2,/,5X,#COOLING USE FACTOR =#	00172
	X	,F5.2,//)	00173
C			00174
		WRITE(IRITE,403)	00175
	403	FORMAT(5X,#COND PRESS AND CORRESPONDING DATA AT EACH CAPACITY	00176
	X#)		00177
		DO 407 I=1,NCAPS	00178
		WRITE(IRITE,404)CAP(I)	00179
	404	FORMAT(/2X,#CAPACITY =#,F4.2)	00180
C			00181
		M2=NHRPTS(I)	00182
		WRITE(IRITE,405)(HRP(I,J),J=1,M2)	00183
	405	FORMAT(3X,#PRESSURE - #,6F8.2)	00184
C			00185
			00186

407	WRITE(IRITE,406) (TURHR(I,J),J=1,M2)	00187
406	FORMAT(3X,#T HEAT RATE = #.6F8.0)	00188
C		00189
	M2=NHRPTS(NCAPS1)	00190
	IF(M2.EQ.0) GO TO 412	00191
	WRITE(IRITE,409) (HRP(NCAPS1,J),J=1,M2)	00192
409	FORMAT(/5X,#DESIGN VALUES (CAPACITY = PLANT SIZE)#.//, 3X, #PR	00193
	XESSURE = #.6F8.2,/))	00194
	WRITE(IRITE,410) (TURBHR(NCAPS1,J),J=1,M2)	00195
410	FORMAT(3X,#T HEAT RATE = #.6F8.0,/))	00196
C		00197
412	WRITE(IRITE,413) TDB,TWB,WIND,RAD,TAVH2O,NH2O	00198
413	FORMAT(#0 DRY BULB T WET BULB T WIND SPEEU RADIATION#/ X F12.0,F14.0,F13.1,F14.0/#0 AVAIL H2O T TYPE AVAILAHLE H2O#/ X F13.0,I16)	00199
C		00200
	WRITE(IRITE,429) PCBASE,TCBASE	00201
429	FORMAT(3X,#BASE P COND BASE T COND#./,7X,F4.2,4X,F4.1//)	00202
	WRITE(IRITE,414) (TAMDB(I),I=1,NTAMB)	00203
414	FORMAT(1H14X#VARIABLE AMBIENT TEMPERATURES#./,3X,#DRY BULB = # X 5F7.0,/))	00204
	WRITE(IRITE,415) (TAMWB(I),I=1,NTAMB)	00205
415	FORMAT(3X,#WET BULB = #.5F7.0,/))	00206
	WRITE(IRITE,416) (TAMRV(I),I=1,NTAMB)	00207
416	FORMAT(3X,#RIVER = #.5F7.0,/))	00208
	WRITE(IRITE,417) (AMWIND(I),I=1,NTAMB)	00209
1417	FORMAT(# WIND#8X,5F7.1)	00210
	WRITE(IRITE,418) (AMRAD(I),I=1,NTAMB)	00211
1418	FORMAT(# RADIATION #5F7.0)	00212
C		00213
	WRITE(IRITE,417)	00214
417	FORMAT(/5X,#PERCENT OF COOLING SYSTEM TIME AT ABOVE#./, X 4X,#AMBIENT CONDITIONS#./)	00215
	DO 418 I=1,NCAPS	00216
418	WRITE(IRITE,419) CAP(I), (PCTAMB(I,J),J=1,NTAMB)	00217
419	FORMAT(/3X,#CAP = #.F4.2,# -#.5F7.2)	00218
C		00219
	WRITE(IRITE,420) WIDTH,NSYSCP,NSPCON	00220
420	FORMAT(/5X, #RIVER WIDTH TYPE COOLING(2=TOPPING) COND S X SPECIFIED(1=YES)#./, 5X,F8.0,14X,I2,24X,I2,/))	00221
C		00222
	IF(NSYSCP=2) 424,421,424	00223
421	WRITE(IRITE,422) TDISMV	00224
422	FORMAT(3X,#MAX DISCHARGE TEMP = #.F4.0,/))	00225
C		00226
424	IF(NSPCON=1) 428,425,428	00227
425	WRITE(IRITE,426) UCVALL,AREAC,SPFLOW	00228
426	FORMAT(5X,#CONDENSER SPECIFICATIONS#./, 3X,#OVERALL U = #.F6. X 0,/, 3X,#TUBE AREA = #.E9.4,/, 3X,#H2O FLOW = #.F9.4,/))	00229
C		00230
428	CONTINUE	00231
	GO TO 60	00232
C		00233
70	CALL SUBPCLU	00234
	GO TO 60	00235
72	CALL SUBPCND	00236
	GO TO 60	00237
74	CALL SUBMDW	00238
	GO TO 60	00239
76	CALL SUBNDW	00240
60	CONTINUE	00241
500	END	00242
		00243
		00244
		00245
		00246
		00247
		00248

	SUBROUTINE SUBPCLU	00249
	COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,CAP(6),TOTLN(5),COLPCT(5),TC	00250
	XMIN(6),PCMIN(6),TCMAX(6),PCMAX(6),HRCCF2(6),HRCCF1(6),HRCCF0(6),	00251
	XTDR,TWB,RH,TAVH2C,TCBASE,NTAMB,AMBDFC(5),AMBDC(5),TAMDB(5),TAMW	00252
	XB(5),AMBRM(5),TAMRV(5),PCTAMR(5,5),NSYSCP,TDISHX,NSPCON,UCVALL,A	00253
	XREAC,SPFLOW,NH2C,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHR,IRITE,IREAD	00254
	WIND=8.8	00255
	QFLRIV=7000.	00256
	DEPTH=10.	00257
	RAD=5580.	00258
	PMPEF=0.8	00259
	TOTCS1=1.E3	00260
C		00261
C	CALCULATION OF THE EQUILIBRIUM TEMPERATURE, TCALC, TO	00262
C	STATEMENT 1 -- EQUATION TAKEN FROM EDINGER	00263
	WCOFA=0.	00264
	WCOFB=15	00265
	ECCF=WCOFA+WCOFB*WIND	00266
	TA=TDB	00267
	TG=TDB	00268
7	DH=RAD-1801.*(TG/460.+1.)**4-ECCF*51.7*(P(TG)-RH*P(TA))-.26*ECC	00269
	X*(TG-TA)	00270
	DHP=RAD-1801.*((TG+1.)/460.+1.)**4-ECCF*51.7*(P(TG+1.)-RH*P(TA))-	00271
	X.26*ECCF*(TG+1.-TA)	00272
	DHM=RAD-1801.*((TG-1.)/460.+1.)**4-ECCF*51.7*(P(TG-1.)-RH*P(TA))-	00273
	X.26*ECCF*(TG-1.-TA)	00274
	DHPRIM=(DHP-DHM)/2.	00275
	IF(ABS(DH)-1.)1,2,2	00276
2	TNEW=TG-DH/DHPRIM	00277
	TG=TNEW	00278
	GO TO 7	00279
1	TCALC=TG	00280
	BETA=51.7*(P(TCALC+1.)-P(TCALC-1.))/2.	00281
	XK=15.7*(0.26*BETA)*ECCF	00282
	TC=TCMIN(NCAPS+1)	00283
100	CONTINUE	00284
	IF(NSPCON-1)30,40,30	00285
40	CALL PAFCST(NCAPS+1,TC,PWCST,DEIFC,QREJ)	00286
	DT2=(QREJ/SPFLOW)/(EXP(UCVALL*AREAC/SPFLOW)-1.)	00287
	DT1=DT2+QREJ/SPFLOW	00288
	T1=TC-DT2	00289
	T2=TC-DT1	00290
	IF(NSYSCP-2)41,46,41	00291
41	IF(DT1-(TC-TAVH2C))45,45,151	00292
30	DT2=5.	00293
	IF(NSYSCP-2)31,46,31	00294
31	T2=TAVH2C	00295
	GO TO 51	00296
46	WRITE(IRITE,50)	00297
50	FORMAT(/#CANNOT HAVE TOPPING WITH STRAIGHT CONDENSER COOLING#)	00298
	GO TO 400	00299
51	CALL PAFCST(NCAPS+1,TC,PWCST,DEIFC,QREJ)	00300
45	CALL COND(TC,T2,QREJ,PWCST,DT2,T1,UA,FLOW,GPM,SYSCST,	00301
	* COSPKW)	00302
	RA=T1-T2	00303
	IF(NH2C)13,14,15	00304
C	PLAC= COST PER KW FOR WATER DUCTING	00305
13	PLAC=1.5	00306
	GO TO 16	00307
14	PLAC=1.25	00308
	GO TO 16	00309
15	PLAC=1.0	00310

16	CONTINUE	00311
	IF (NSPCON.EQ.1) PLAC=0.0	00312
	SYSCST=SYSCST+PLAC*ANFCR/(CAPFAC*8.76)	00313
C	ASSUME 5 FT OF PUMPING HEAD (FRICTION)	00314
	PHEAD=5.	00315
	HPPMP=GPM*PHEAD/(3960.*PMPEF)	00316
	CAPCOS=0.0	00317
	OPCOS=(HPPMP*.7457/(PSIZE*1000.))*PW CST	00318
	COSMAI=.001*CAPCOS/(PSIZE*1000.)*.1*OPCOS+.01*SYSCST	00319
	TOTCOS=SYSCST+DELFC+OPCOS+COSMAI	00320
	IF (TOTCOS-TOTCS1) 154,156,156	00321
156	IF (NSPCON.EQ.1) GO TO 190	00322
151	TC=TC+1.	00323
	IF (TC-TCHMAX(NCAPS+1)) 100,100,190	00324
154	RA1=RA	00325
	T11=T1	00326
	T21=T2	00327
	SYS1=SYSCST	00328
	CAPCS1=CAPCOS	00329
	COSPK1=COSPKW	00330
	OPCS1=OPCOS	00331
	COSMA1=COSMAI	00332
	PLAC1=PLAC	00333
	HPF1=0.	00334
	HPP1=HPPMP	00335
	DELFI=DELFC	00336
	TCALC1=TCALC	00337
	QRJ1=QREJ	00338
	FLOW1=FLOW	00339
	FCFS=FLOW1/224700.	00340
	GPM1=GPM	00341
	UA1=UA	00342
	TC1=TC	00343
	TOTCS1=TOTCOS	00344
	GO TO 156	00345
190	IF (TOTCS1-1.E3) 200,195,200	00346
195	WRITE (IRITE,196) TC,T1,RA	00347
196	FORMAT (/3X, #FOR THE GIVEN CONDITIONS A SOLUTION CANNOT BE FOUND	00348
	XD#/,3X,#TC =#,F5.0,# T1 =#,F5.0,# RA =#,F5.0)	00349
	GO TO 400	00350
200	CONTINUE	00351
	WRITE (IRITE,212)	00352
212	FORMAT (#1#15X#-----STRAIGHT CONDENSER COOLING-----#/,)	00353
	IF (NH2C) 220,228,230	00354
220	WRITE (IRITE,197)	00355
197	FORMAT (20X#(WITH SEA WATER)#//)	00356
	GO TO 23	00357
228	WRITE (IRITE,198)	00358
198	FORMAT (20X#(WITH UNTREATED FRESH WATER)#//)	00359
	GO TO 23	00360
230	WRITE (IRITE,157)	00361
157	FORMAT (20X#(WITH TREATED FRESH WATER)#//)	00362
23	WRITE (IRITE,227) QRJ1,TC1,FCFS,FLOW1,HPP1,TCALC1,RA1	00363
227	FORMAT (10X#THE DESIGN VALUES AND COSTS ARE -#/,3X#Q REJECT =	00364
	X#,E9.4,# BTU/HR AT T CONDENSER =#,F4.0,/,3X#CONDENSER FLOW =#,E9.	00365
	* 4,# CFS (#E9.	00366
	X4,# LB/HR) PUMP POWER =#,E9.4,# HP#/,3X#EQUILIRIUM TEMP =#,F4.0	00367
	X,# RANGE =#,F4.0,/))	00368
	CALL PRDTS2(CAPCS1,OPCS1,COSMA1,SYS1,DELFI,TOTCS1,COSPK1)	00369
	WRITE (IRITE,302)	00370
302	FORMAT (//15X#--RIVER TEMPERATURES--#/,)	00371
	X1X,14HDISTANCE-MILES,3X,17HSTREAM TEMP DEG.F, 3X,17HPLIIME TEMP.-DE	00372

```

      XG.F .3X,14HPLUME WIDTH=MI./19X,8HNO PLANT,2X,5HMTXED.//)
C      CALC OF PLUME TEMPS AND WIDTH AND RIVER TEMPS- TC STAT 22
      VELRIV=(QFLRIV/(WIDTH*DEPTH))*3600.*24.
      DTRIV=(QRJ1/QFLRIV)/(3600.*62.4)
      TZERO=TAVH20+DTRIV
      I=-1
307 I=I+1
      IF(I.EQ.11)I=20
      XI=I
      QCON=FLOW1/(3600.*62.4)
      C1=ALOG(QFLRIV/(QFLRIV-QCON))
      PLUMFW=WIDTH*(1.-EXP(-(XI/2.*C1)))
      ALPHA1=((XK*XI+5280.)/(62.4*DEPTH*VELRIV))
      TXDIST=(TZERO-TCALC)*EXP(ALPHA1)+TCALC
      TWREAL=(TAVH20-TCALC)*EXP(ALPHA1)+TCALC
      PLUMEW=PLUMFW/5280.
      PLUMT=((TXDIST-TWREAL)/(1.-EXP(-(XI/2.*C1))))+TWREAL
      WRITE(IRITE,308)XI,TWREAL,TXDIST,PLUMT,PLUMEW
308 FORMAT(6X,F5.1,6X,F6.2,4X,F6.2,5X,F6.2,11X,F6.4)
      IF(I.LT.20)GO TO 307
      WRITE(IRITE,330)
330 FORMAT(/15X,#VARIABLE AMBIENT CONDITIONS#/)
      IF(NTAMB.EQ.0)GO TO 400
      TSPMIL=0.0
      TDFMIL=0.0
      DO 350 I=1,NCAPS
      IF(CAP(I).EQ.0.)GO TO 350
      AMBOPC(I)=0.0
      AMBDFC(I)=0.0
      DO 340 J=1,NTAMB
      IF(PCTAMB(I,J).EQ.0.)GO TO 340
      TC=TCHIN(I)
      NTCOD=0
301 CALL PAFST(I,TC,PWCST,DFCOD,QREJ)
      DT2=(QREJ/FLOW1)/(EXP(UAL/FLOW1)-1.)
      DT1=DT2+QREJ/FLOW1
      T1=TC-DT2
      T2=TC-DT1
      IF(T2-TAMRV(J))304,305,310
305 NTCOD=1
      GO TO 310
304 TC=TC+1.
      NTCOD=1
      IF(TC.LT.TCMAX(I))GO TO 301
      WRITE(IRITE,309)PCMAX(I),CAP(I),TAMWB(J)
309 FORMAT(/,3X,#CONDENSER PRESS MUST EXCEED THE GIVEN MAX CF#/,8
      XX,F4.2,# FOR THE CAPACITY CF#,F4.2,# AT T WET BULB =#,F5.0,/,3X,#P
      XROGRAM DISCONTINUING#)
      GO TO 400
310 IF(NTCOD.GT.0)GO TO 315
      WRITE(IRITE,312)CAP(I),TAMWB(J),TC
312 FORMAT(/8X,#FOR CAP =#,F4.2,#, T WB =#,F5.0,#, AND TC =#,
      XF4.0,/,3X#PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE#)
      IF(DFCOD.GT.0.)DFCOD=0.0
315 CONTINUE
      QPCOD=(HPP1*.7457/(PSIZE*1000.))*PWCST
      AMBOPC(I)=AMBOPC(I)+QPCOD*PCTAMB(J)
      AMBDFC(I)=AMBDFC(I)+DFCOD*PCTAMB(J)
340 CONTINUE
      TSPMIL=TSPMIL+AMBOPC(I)*TCTLD(I)*COLPCT(I)*CAP(I)
      TDFMIL=TDFMIL+AMBDFC(I)*TCTLD(I)*COLPCT(I)*CAP(I)
350 CONTINUE

```

AVOPCS=TOPMIL/TKWHRS
AVDFCS=TOPMIL/TKWHRS
AVTCST=AVOPCS+AVDFCS+SYS1+COSMA1
CALL PRTOO (AVOPCS,AVDFCS,AVTCST)
400 CONTINUE
RETURN
END

00435
00436
00437
00438
00439
00440
00441

	SUBROUTINE SUBCOND	00442
	COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,CAP(6),TOTLN(5),COLPCT(5),TC	00443
	XMIN(6),PCMIN(6),TCMAX(6),PCMAX(6),HRCOF2(6),HRCOF1(4),HRCOF0(6),	00444
	XTDB,TWB,RH,TAVH2O,TCBASE,NTAMB,AMBDFC(5),AMBOPC(5),TAMDB(5),TAMW	00445
	XB(5),AMRRH(5),TAMRV(5),PCTAMB(5,5),NSYSCP,TDISMX,NSPCON,UCVALL,4	00446
	XREAC,SPFLOW,NH2O,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHRS,WRITE,IREAD,	00447
	* AMWIND(5),AMRAD(5),WIND,RAD	00448
	PMPEF=0.8	00449
	TOTCS1=1.E3	00450
C	CALC OF EQUILIBRIUM TEMPERATURE	00451
	WCOFA=0.	00452
	WCOFB=15.	00453
	ECCF=WCOFA+WCOFB*WIND	00454
	TA=TDB	00455
	TG=TDB	00456
7	DH=RAD-1801.*(TG/460.+1.)**4-ECCF*51.7*(P(TG)-RH*P(TA))-.26*ECC	00457
	X*(TG-TA)	00458
	DHP=RAD-1801.*((TG+1.)/460.+1.)**4-ECCF*51.7*(P(TG+1.)-RH*P(TA))-	00459
	X.26*ECCF*(TG+1.-TA)	00460
	DHM=RAD-1801.*((TG-1.)/460.+1.)**4-ECCF*51.7*(P(TG-1.)-RH*P(TA))-	00461
	X.26*ECCF*(TG-1.-TA)	00462
	DHPRIM=(DHP-DHM)/2.	00463
	IF(ABS(DH)-1.)1,2,2	00464
2	TNEW=TG-DH/DHPRIM	00465
	TG=TNEW	00466
	GO TO 7	00467
1	TCALC=TG	00468
	BETA=51.7*(P(TCALC+1.)-P(TCALC-1.))/2.	00469
	XK=15.7*(0.26*BETA)*ECCF	00470
	TC=TCMIN(NCAPS+1)	00471
100	CONTINUE	00472
	IF(NSPCON-1)30,40,30	00473
40	CALL PAFCST(NCAPS+1,TC,PWCST,DELFC,QREJ)	00474
	DT2=(QREJ/SPFLOW)/(EXP(UCVALL*AREAC/SPFLOW)-1.)	00475
	DT1=DT2*QREJ/SPFLOW	00476
	T1=TC-DT2	00477
	IF(NSYSCP-2)44,41,44	00478
41	IF(TDISMX.LT.TCALC)GO TO 197	00479
	IF(DT1-(TC-TAVH2O))15,15,42	00480
42	IF(TC-TCMAX(NCAPS+1))13,190,190	00481
13	TC=TC+1	00482
	GO TO 40	00483
15	T2=TDISMX	00484
	RA=T1-T2	00485
	IF(RA.LT.0.)GO TO 190	00486
	GO TO 46	00487
44	T2=TC-DT1	00488
	IF(T2-TCALC)151,151,45	00489
30	DT2=5.	00490
	IF(NSYSCP-2)31,32,31	00491
31	T2=TCALC+1.	00492
	GO TO 50	00493
32	IF(TDISMX.LT.TCALC)GO TO 197	00494
	T2=TDISMX	00495
50	IF((TC-DT2)-T2)151,151,51	00496
51	CALL PAFCST(NCAPS+1,TC,PWCST,DELFC,QREJ)	00497
	IF(NSYSCP-2)45,46,45	00498
45	CALL COND(TC,T2,QREJ,PWCST,DT2,T1,UA,FLOW,GPM,SYSCST,COSPKW)	00499
	QREJT=QREJ	00500
	GO TO 47	00501
46	CALL COND(TC,TAVH2O,QREJ,PWCST,DT2,T1,UA,FLOW,GPM,SYSCST,COSPKW)	00502
	QREJT=QREJ*(T1-T2)/(T1-TAVH2O)	00503

47	RA=T1-T2	00504
	ALPHA=-LOG((T2-TCALC)/(T1-TCALC))	00505
	AREAP=24.*ALPHA*FLOW/(XK*43560.)	00506
C	ALOG MEAN T DIF BETWEEN AIR AND WATER	00507
	IF(T2-TDB)48,48,49	00508
48	WLMTD=(T1+T2)/2.-TDB	00509
	GO TO 53	00510
49	WLMTD=(T1-T2)/ALOG((T1-TDR)/(T2-TDR))	00511
C	BOWEN RATIO - RATIO OF CONDUCTION TO EVAPORATION	00512
C	HEAT TRANSFER - MODIFIED FROM EDINGER AND GEYER	00513
53	TWAV=(T1+T2)/2.	00514
	BCWRAT=.26*WLMTD/(51.7*(P(TWAV)-RH*P(TDR)))	00515
	QLAT=(QREJT-(.173E-8*((T1+T2)/2.-460.))**4-RAD/24.)*AREAP*	00516
	* 43560.)/(1.+BCWRAT)	00517
	WEVAP=QLAT/970.3	00518
	GPMT=GPM+WEVAP/(8.34*60.)	00519
C	ASSUME 30 FT OF PUMPING HEAD (FRICTION)	00520
	PHEAD=30.	00521
	HPPMP=GPMT*PHEAD/(3960.*PMPEF)	00522
	CAPCOS=AREAP*PRPAGR	00523
	DELFC=DELFC*USEFAC	00524
	OPCOS=(HPPMP*.7457/(PSIZE*1000.))*PWCST*USEFAC	00525
	COSMAI=.001*CAPCOS/(PSIZE*1000.)*.1*OPCOS+.01*SYS CST	00526
	TOTCOS=(CAPCOS*ANFCR)/(PSIZE*1000.*CAPFAC*8.76) +OPCOS +COSMAI+SYS	00527
	XCST=DELFC	00528
	IF(TOTCOS-TOTCS1)154,156,156	00529
156	IF(NSPCON.EQ.1)GO TO 157	00530
	IF(NSYSOP.EQ.2)GO TO 151	00531
	T2=T2+1.	00532
	GO TO 50	00533
157	IF(NSYSOP.EQ.2)GO TO 190	00534
151	TC=TC+1.	00535
	IF(TC-TCMAX(NCAPS+1))100,100,190	00536
154	RA1=RA	00537
	AREAP1=AREAP	00538
	T11=T1	00539
	T21=T2	00540
	SYS1=SYS CST	00541
	CAPCS1=CAPCOS	00542
	COSPK1=COSPKW	00543
	OPCS1=OPCOS	00544
	COSMA1=COSMAI	00545
	AFLR1=.7.	00546
	HPF1=.0.	00547
	HPP1=HPPMP	00548
	DELFI=DELFC	00549
	TCALC1=TCALC	00550
	QRJ1=QREJ	00551
	QRJT1=QREJT	00552
	FLOW1=FLOW	00553
	GPM1=GPM	00554
	UA1=UA	00555
	WEVAP1=WEVAP	00556
	TC1=TC	00557
	TOTCS1=TOTCOS	00558
	GO TO 156	00559
190	IF(TOTCS1-1.E3)200,195,200	00560
195	WRITE(IRITE,196)TC,T1,RA	00561
196	FORMAT(/3X, #FOR THE GIVEN CONDITIONS A SOLUTION CANNOT BE FOUN	00562
	XD#./,3X, #TC =#,F5.0, # T1 =#,F5.0, # RA =#,F5.0)	00563
	GO TO 400	00564
197	WRITE(IRITE,198)	00565

198	FORMAT(/,3X,#MAX DIS T LESS THAN EQUILIRIUM T#)	00566
	GO TO 400	00567
200	CONTINUE	00568
	WRITE(IRITE,212)	00569
212	FORMAT(#1#,15X,#---- COOLING POND ----#,//, 10X, #THE DESIGN V	00570
	XVALUES AND COSTS ARE -,//)	00571
	CALL PRDTS1(QRJ1,TC1,HPP1,HPP1,WEVAP1,WRDWN1,AFLH1)	00572
	WRITE(IRITE,227)FLOW1,T11,RA1,TCALC1,ARFAP1	00573
227	FORMAT(3X,#COND FLOW =#,E9.4,# T IN =#,F4.0,# RANGE =#	00574
	X,F4.0,/,3X,#EQUILIRIUM TEMP =#,F4.0,# POND AREA =#,F4.0,	00575
	X# ACRES#)	00576
	IF(NSYSCP-2)230,228,230	00577
228	WRITE(IRITE,229)QRJT1	00578
229	FORMAT(/3X,#Q REJ POND =#,E9.4,# BTU/HR#)	00579
230	CALL PRDTS2(CAPCS1,OPCS1,COSMA1,SYSL,DFLF1,TOTCS1,COSPK1)	00580
	WRITE(IRITE,330)	00581
330	FORMAT(/,15X,#VARIABLE AMBIENT CONDITIONS#)	00582
	IF(NTAMB,EQ.0)GO TO 400	00583
	TCPMIL=0.0	00584
	TDFMIL=0.0	00585
	DO 350 J=1,NCAPS	00586
	IF(CAP(J).EQ.0.)GO TO 350	00587
	AMRCP(J)=0.0	00588
	AMRDFC(J)=0.0	00589
	DO 340 J=1,NTAMB	00590
	IF(PCTAMB(I,J).EQ.0.)GO TO 340	00591
	TC=TCMIN(I)	00592
	NTCOD=0	00593
	TA=TAMDB(J)	00594
	TG=TA	00595
	RAD=AMRAD(J)	00596
	ECOF=WCOFA+WCOFB*AMWIND(J)	00597
20	DH=RAD-1801.*(TG/460.+1.)**4-ECOF*51.7*(P(TG)-AMBRH(J)*P(TA))-	00598
	X.26*ECOF*(TG-TA)	00599
	DHP=RAD-1801.*((TG+1.)/460.+1.)**4-ECOF*51.7*(P(TG+1.)-AMBRH(J)*	00600
	XP(TA))-26*ECOF*(TG+1.-TA)	00601
	DHM=RAD-1801.*((TG-1.)/460.+1.)**4-ECOF*51.7*(P(TG-1.)-AMBRH(J)*	00602
	XP(TA))-26*ECOF*(TG-1.-TA)	00603
	DHPRIM=(DHP-DHM)/2.	00604
	IF(ABS(DH)-1.)21,22,22	00605
22	TNEW=TG-DH/DHPRIM	00606
	TG=TNEW	00607
	GO TO 20	00608
21	TCALC=TG	00609
	BETA=51.7*(P(TCALC+1.)-P(TCALC-1.))/2.	00610
	XK=15.7*(.26*BETA)*ECOF	00611
	ALPACT=(AREAP1*XK*43560.)/(24.*FLOW1)	00612
301	CALL PAFCS1(I,TC,PWCST,DFCOD,GRE.1)	00613
	DT2=(GREJ/FLOW1)/(EXP(UA1/FLOW1)-1.)	00614
	DT1=DT2*GREJ/FLOW1	00615
	T1=TC-DT2	00616
	T2=TC-DT1	00617
	IF(NSYSCP-2)316,303,316	00618
316	IF(T2-TCALC)304,304,302	00619
303	IF(T2-TAMRV(J))304,305,306	00620
305	NTCOD=1	00621
	GO TO 306	00622
306	T2=TCALC*(T1-TCALC)/EXP(ALPACT)	00623
	IF(T2-TDISMX)310,310,307	00624
307	WRITE(IRITE,308)CAP(I),TAMWB(J),TC,T2	00625
308	FORMAT(/8X#FOR CAP =#,F4.2,# T WB =#,F4.0,# AND TC =#	00626
	X,F4.0,/,3X#T DIS EXCEEDS TDIS MAX - CONTINUING#)	00627

GO TO 315	
302 ALPHA=-ALOG((T2-TCALC)/(T1-TCALC))	00628
IF (ALPHA.LT.ALPACT) GO TO 310	00629
304 TC=TC+1.	00630
NTCCD=1	00631
IF (TC .LT. TCMAX(I)) GO TO 301	00632
WRITE (IRITE,309) CAP(I).J	00633
309 FORMAT(*-*****THE PCND IS ESSENTIALLY TOO SMALL FOR*,F4.2,	00634
* * CAPACITY AND AMBIENT NO.*,I2/* PROGRAM DISCONTINUING*)	00635
GO TO 400	00636
310 IF (NTCCD.GT.0) GO TO 315	00637
WRITE (IRITE,312) CAP(I).J	00638
312 FORMAT(*OTHE PCND IS LARGER THAN NECESSARY FOR*,F4.2,* CAPACITY*,	00639
* * AND AMBIENT NO.*,I2/	00640
* * COMPUTING COSTS ASSUMING MOST EFFICIENT CONDITION (PC=PCMIN)*)	00641
IF (DECCD.GT.0.) DFCCD=0.0	00642
315 CONTINUE	00643
GPCCD=(HPP1*.7457/(PSIZE*1000.))*PWCST	00644
AMBOPC(I)=AMBOPC(I)+GPCCD*PCTAMB(J)	00645
AMBDPC(I)=AMBDPC(I)+DFCCD*PCTAMB(J)	00646
340 CONTINUE	00647
TOPMIL=TOPMIL+AMBOPC(I)*TOTLD(I)*COLPCT(I)*CAP(I)	00648
TDFMIL=TDFMIL+AMBDPC(I)*TOTLD(I)*COLPCT(I)*CAP(I)	00649
350 CONTINUE	00650
AVOPCS=TOPMIL/TKWHRS	00651
AVDFCS=TDFMIL/TKWHRS	00652
AVTCST=(CAPCS1*ANFCR)/(PSIZE*1000.*CAPFAC*8.76) +AVOPCS+AVDFCS+SYS	00653
X1=CCSMAL	00654
CALL PRTOC(AVOPCS,AVDFCS,AVTCST)	00655
400 CONTINUE	00656
RETURN	00657
END	00658
	00659

SUBROUTINE SUBMDW	00660
COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,UA,TC	00661
X COLPCT(5),TCMIN(6),PCMIN(6),TCMAX(6),PCMAX(6),	00662
X HRCCF2(6),HRCCF1(6),HRCCF0(6),TDB,TWR,RH,TAVH20,TCRASE,	00663
X NTAMB,AMBDFC(5),AMBGPC(5),TAMDR(5),TAMWR(5),AMRRH(5),	00664
X TAMRV(5),PCTAMB(5,5),NSYSCP,TDISMV,NSPCCN,UCVALL,AREAC,SPFLOW,	00665
X NH20,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHR,IRITE,IHEAD	00666
DIMENSION XK(20)	00667
FANEF=0.8	00668
PMPEF=0.8	00669
TOTCS1=1.E3	00670
TC=TCMIN(NCAPS+1)	00671
100 CONTINUE	00672
IF(NSPCCN-1)30,40,30	00673
40 CALL PAFCST(NCAPS+1,TC,PWCST,DELFC,QREJ)	00674
DT2=(QREJ/SPFLOW)/(EXP(UCVALL*AREAC/SPFLOW)-1.)	00675
DT1=DT2+QREJ/SPFLOW	00676
T1=TC-DT2	00677
IF(NSYSCP-2)44,41,44	00678
41 IF(DT1-(TC-TAVH20))15,15,42	00679
42 IF(TC-TCMAX(NCAPS+1))13,190,190	00680
13 TC=TC+1	00681
GO TO 40	00682
15 T2=TDISMV	00683
APPR=T2-TWB	00684
IF(APPR.LT.7.)GO TO 190	00685
IF(APPR.GT.20.)GO TO 190	00686
RA=T1-T2	00687
IF(RA.LT.10.)GO TO 190	00688
GO TO 46	00689
44 T2=TC-DT1	00690
APPR=T2-TWB	00691
IF(APPR.LT.7.)GO TO 151	00692
IF(APPR.GT.20.)GO TO 190	00693
GO TO 45	00694
30 IF(NSYSCP-2)31,32,31	00695
31 APPR=7.	00696
50 T2=TWR+APPR	00697
IF(TC-T2)151,151,51	00698
32 T2=TDISMV	00699
APPR=T2-TWB	00700
IF(APPR.LT.7.)GO TO 190	00701
IF(APPR.GT.20.)GO TO 190	00702
51 DT2=5.	00703
CALL PAFCST(NCAPS+1,TC,PWCST,DELFC,QREJ)	00704
IF(NSYSCP-2)45,46,45	00705
45 CALL COND(TC,T2,QREJ,PWCST,DT2,T1,UA,FLOW,GPM,SYSCST,	00706
* COSPKW)	00707
QREJT=QREJ	00708
GO TO 47	00709
46 CALL COND(TC,TAVH20,QREJ,PWCST,DT2,T1,UA,FLOW,GPM,SYSCST,	00710
* COSPKW)	00711
QREJT=QREJ*(T1-T2)/(T1-TAVH20)	00712
47 RA=T1-T2	00713
IF(RA.LT.10.)GO TO 151	00714
TAXT=(T1+T2)/2.	00715
H1=H(TWB)	00716
H2=H(TAXT)	00717
AFLR=QREJT/(H2-H1)	00718
WACT=RH*(.622*P(TDB))/(14.696-P(TDB))	00719
APSAT=(WACT*14.696)/(1.622+WACT)	00720
DIN=144.*(14.696-APSAT)/(53.35*(TDB+460.))	00721

	WART=FLOW/AFLR	00722
	T3=T2+.1*RA	00723
	T4=T2+.4*RA	00724
	T5=T1-.4*RA	00725
	T6=T1-.1*RA	00726
	CO1=WART*RA	00727
	RDH1=1./(H(T3)-H1-.1*CO1)	00728
	RDH2=1./(H(T4)-H1-.4*CO1)	00729
	RDH3=1./(H(T5)-H2+.4*CO1)	00730
	RDH4=1./(H(T6)-H2+.1*CO1)	00731
	CHAR=(RA/4.)*(RDH1+RDH2+RDH3+RDH4)	00732
C		00733
C	PACKING HEIGHT FROM FRAAS + CZISIK = DECK NUMBER 1	00734
	DECKHT =2.	00735
	PHT=DECKHT*(CHAR-.07)/(1.103*WART*(-.54))	00736
C	WATER LOADING = 2500	00737
	WLOAD=2500.	00738
	PLANA=FLOW/WLOAD	00739
C	AIR LOADING OR G	00740
	ALDG=AFLR/PLANA	00741
	ALDGE=ALDG+3500.	00742
C		00743
C	PRESSURE DROP (INCHES OF WATER) FROM FRAAS AND CZISIK	00744
	DELP=((PHT/DECKHT)*.0675/DIN)*(0.4E-R*ALDG**2+.1E-12*2500.*ALDGE*	00745
	X*2*2.62)	00746
	RANGE=RA	00747
	IK=APPR	00748
	IF (GPM) 210,210,11	00749
C	CALK OF K FACTOR - LOCKHART ET AL	00750
11	IF (IK-7) 370,7,1	00751
1	IF (IK-20) 2,2,370	00752
2	IF (IK-10) 6,5,5	00753
6	GO TO (8,9),(IK-7)	00754
7	XK(7)=.42626139+.30755494*RANGE-.83222851E-02*RANGE**2+.14	00755
	X130379E-03*RANGE**3-.87533682E-06*RANGE**4	00756
	GO TO 25	00757
8	XK(8)=.53003286+.26855945*RANGE-.71968070E-02*RANGE**2+.12	00758
	X092005E-03*RANGE**3-.73568322E-06*RANGE**4	00759
	GO TO 25	00760
9	XK(9)=.27667081+.27125055*RANGE-.75042365E-02*RANGE**2+.12	00761
	X884963E-03*RANGE**3-.80021940E-06*RANGE**4	00762
	GO TO 25	00763
5	AA=APPR/2.	00764
	Z=0.	00765
	IA=AA	00766
	AB=IA	00767
	IF (AB.EQ.AA) GO TO (10,12,14,16,18,20),(AB-4.)	00768
	GO TO (10,12,14,16,18),(AB-4.)	00769
21	Z=2.	00770
	GO TO (12,14,16,18,20),(AB-4.)	00771
10	XK(10)=.87557520E-01+.25976379*RANGE-.69589515E-02*RANGE**2	00772
X	+.11542869E-03*RANGE**3-.69832755E-06*RANGE**4	00773
	IF (AB.EQ.AA) GO TO 25	00774
	IF (Z-2.) 21,23,21	00775
12	XK(12)=.30755983E-02+.22692621*RANGE-.57515664E-02*RANGE**2	00776
X	+.89248959E-04*RANGE**3-.50381046E-06*RANGE**4	00777
	IF (AB.EQ.AA) GO TO 25	00778
	IF (Z-2.) 21,23,21	00779
14	XK(14)=.33616133+.22612638*RANGE-.57931043E-02*RANGE**2	00780
X	+.89896029E-04*RANGE**3-.50893025E-06*RANGE**4	00781
	IF (AB.EQ.AA) GO TO 25	00782
	IF (Z-2.) 21,23,21	00783

16	XK(16)=-.43379805+.20785695*RANGE-.51672632E-02*RANGE**2	00784
	X+.77053656E-04*RANGE**3-.42119093E-06*RANGE**4	00785
	IF(AR.EQ.AA)GO TO 25	00786
	IF(Z-2.)21,23,21	00787
18	XK(18)=-.91434163+.23827008*RANGE-.66801246E-02*RANGE**2	00788
	X+.10604073E-03*RANGE**3-.61338627E-06*RANGE**4	00789
	IF(AR.EQ.AA)GO TO 25	00790
	IF(Z-2.)21,23,21	00791
20	XK(20)=-.12250402E+01+.25793956*RANGE-.7655059E-02*RANGE**2	00792
	X+.12169709E-03*RANGE**3-.70610963E-06*RANGE**4	00793
	IF(AR.EQ.AA)GO TO 25	00794
	IF(Z-2.)21,23,21	00795
23	XK(IK)=(XK(IK-1)+XK(IK+1))/2.	00796
25	CONTINUE	00797
	CWB=.7*EXP(4.17-.0767*TWB)	00798
	DELHS=QREJT/AFLR	00799
	HCUT=H1+DELHS	00800
	TCUTS=.99674408E1+.24105952E1*HCUT-.22686654E-1*HCUT**2 +.102553	00801
	X04E-3*HCUT**3-.14174090E-6*HCUT**4	00802
	QLAT=QREJT-AFLR*.24*(TCUTS-TDB)	00803
	WEVAP=QLAT/970.3	00804
	CONCR=5.	00805
C	WATER FOR BLOWDOWN	00806
	WBDWN=(.06*QREJT*62.4)/(500.*7.48*(CONCR-1.))	00807
	WNEED=WEVAP+WBDWN	00808
	GPMT=GPM+WNEED/(8.34*60.)	00809
	FUDGE=GPMT*XK(IK)*CWB	00810
C	LOCKHART SAYS COST = 2*FUDGE BUT CONVERSES COSTS ARE	00811
C	ABOUT 2*LOCKHARTS - USE AVG. = 3*FUDGE	00812
	CAPCOS=3.*FUDGE	00813
	ACFM=AFLR/(60.*DIN)	00814
	HPFAN=(ACFM*DELP*5.2)/(33000.*FANEF)	00815
	HPPMP=GPMT*(PHT+10.)/(3960.*PMPEF)	00816
	TCTHP=HPFAN+HPPMP	00817
	DELFC=DELFC*USEFAC	00818
	GPCOS=(TCTHP*.7457/(PSIZE*1000.))*PWCS*USEFAC	00819
	COSMAI=.001*CAPCOS/(PSIZE*1000.)*.1*PCOS*.01*SYSCST	00820
	TCTCOS=(CAPCOS*ANFCR)/(PSIZE*1000.*CAPFAC*8.76)*GPCOS	00821
	X+COSMAI+SYSCST+DELFC	00822
	IF(TCTCOS-TCTCS)154,156,156	00823
156	IF(NSPCON.EQ.1)GO TO 157	00824
	IF(NSYSCP.EQ.2)GO TO 151	00825
	APPR=APPR+1.	00826
	IF(APPR-20.)50,50,151	00827
157	IF(NSYSCP.EQ.2)GO TO 190	00828
151	TC=TC+1.	00829
	IF(TC-TCMAX(NCAPS+1))100,100,190	00830
154	RAI=RA	00831
	CHARI=CHAR	00832
	PHTI=PHT	00833
	PLANAI=PLANA	00834
	AFLRI=AFLR	00835
	DPLI=DELP	00836
	APPRI=APPR	00837
	HWBI=H1	00838
	SYSI=SYSCST	00839
	CAPCS1=CAPCOS	00840
	COSPK1=COSPKW	00841
	GPCS1=GPCOS	00842
	COSMAI=COSMAI	00843
	THP1=TCTHP	00844
	HPFI=HPFAN	00845

HPP1=HPPMP	00846
DELF1=DELFC	00847
QRJ1=QREJ	00848
QRJT1=QREJT	00849
FLOW1=FLOW	00850
GPM1=GPM	00851
WART1=WART	00852
UA1=UA	00853
WEVAP1=WEVAP	00854
WBDWN1=WBDWN	00855
WNEED1=WNEED	00856
TC1=TC	00857
XK1=XK(IK)	00858
TOTCS1=TOTCOS	00859
GO TO 156	00860
190 IF(TOTCS1-1.E3)200,195,200	00861
195 WRITE(IRITE,196)TC,APPR,RA	00862
196 FORMAT(/3X,#FOR THE GIVEN CONDITIONS A SOLUTION CANNOT BE	00863
X FOUND#./,3X,#TC =#,F5.0,# APPR =#,F5.0,# RA =#,F5.0)	00864
GO TO 400	00865
200 CONTINUE	00866
210 WRITE(IRITE,212)	00867
212 FORMAT(#1#.15X,#----- MECHANICAL DRAFT WET TOWER -----#./, 10	00868
XX,#THE DESIGN VALUES AND COSTS ARE -#./,)	00869
CALL PRDTS1(QRJ1,TC1,HPP1,HPP1,WEVAP1,WBDWN1,AFLP1)	00870
WRITE(IRITE,227)DP1,FLOW1,RA1,APPR1	00871
227 FORMAT(3X,#PRESSURE DROP =#,F5.2,# COND FLOW =#,E9.4,/,	00872
X 3X#RANGE =#,F4.0,# APPROACH =#,F4.0)	00873
IF(NSYSCP-2)230,228,230	00874
228 WRITE(IRITE,229)QRJT1	00875
229 FORMAT(/3X,#Q REJ TOWER =#,E9.4,# BTU/HR#)	00876
230 CALL PRDTS2(CAPCS1,OPCS1,COSMA1,SYSC1,DELF1,TOTCS1,COSPK1)	00877
WRITE(IRITE,330)	00878
330 FORMAT(/15X,#VARIABLE AMBIENT CONDITIONS#)	00879
IF(NTAMB.EQ.0)GO TO 400	00880
TCPM1L=0.0	00881
TDFM1L=0.0	00882
DO 350 I=1,NCAPS	00883
IF(CAP(I).EQ.0.)GO TO 350	00884
AMBCPC(I)=0.0	00885
AMBDPC(I)=0.0	00886
DO 340 J=1,NTAMB	00887
IF(PCTAMB(I,J).EQ.0.)GO TO 340	00888
TC=TCMIN(I)	00889
NTCCD=0	00890
301 CALL PAFCS1(I,TC,PWCST,DFCCD,QREJ)	00891
DT2=(QREJ/FLOW1)/(EXP(UA1/FLOW1)-1.)	00892
DT1=DT2+QREJ/FLOW1	00893
T1=TC-DT2	00894
T2=TC-DT1	00895
IF(NSYSCP-2)316,303,316	00896
316 IF(T2-TAMWB(J))304,304,302	00897
303 IF(T2-TAMRV(J))304,305,306	00898
305 NTCOD=1	00899
306 T2=TDISM4X	00900
IF(T2.GT.TAMWB(J))GO TO 302	00901
WRITE(IRITE,313)TAMWB(J)	00902
313 FORMAT(3X#T DIS MAX LESS THAN(OP =) T WB =#,F4.0,/,	00903
X 3X#REQUIRES NEGATIVE APPROACH - DISCONTINUING#)	00904
GO TO 400	00905
302 TAXT=(T1+T2)/2.	00906
RA=T1-T2	00907

T3=T2+.1*RA	00908
T4=T2+.4*RA	00909
T5=T1-.4*RA	00910
T6=T1-.1*RA	00911
CC1=WART1*RA	00912
H1=H(TAMWB(J))	00913
H2=H(TAXT)	00914
RDH1=1./(H(T3)-H1-.1*CC1)	00915
RDH2=1./(H(T4)-H1-.4*CC1)	00916
RDH3=1./(H(T5)-H2+.4*CC1)	00917
RDH4=1./(H(T6)-H2+.1*CC1)	00918
CHAR=(RA/4.)*(RDH1+RDH2+RDH3+RDH4)	00919
IF(CHAR.LT.CHAR1) GO TO 310	00920
IF(INSYSP-2) 304,307,304	00921
307 WRITE(IRITE,308)CAP(I),TAMWB(J),TC	00922
308 FORMAT(/8X,FCR CAP =#,F4.2,%, T WR =#,F4.0,%, AND	00923
X TC =#,F4.0,/,3X,T DIS EXCEEDS TDIS MAX - CONTINUING#)	00924
GO TO 315	00925
304 TC=TC+1.	00926
NTCCD=1	00927
IF(TC.LT.TCMAX(I))GO TO 301	00928
WRITE(IRITE,309)PCMAX(I),CAP(I),TAMWB(J)	00929
309 FORMAT(/,3X,CONDENSER PRESS MUST EXCEED THE GIVEN MAX OF#,/ R	00930
XX,F4.2,%, FOR THE CAPACITY OF#,F4.2,%, AT T WET BULB =#,F5.0,/,3X,%,	00931
XPROGRAM DISCONTINUING#)	00932
GO TO 400	00933
310 IF(NTCCD.GT.0)GO TO 315	00934
WRITE(IRITE,312)CAP(I),TAMWB(J),TC	00935
312 FORMAT(/8X,FCR CAP =#,F4.2,%, T WR =#,F5.0,%, AND	00936
X TC =#,F4.0,/,3X,PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE#)	00937
IF(DFCCD.GT.0.)DFCCD=0.0	00938
315 CONTINUE	00939
CPCCD=(THP1*.7457/(PSIZE*1000.))*PWCST	00940
AMBOPC(I)=AMBOPC(I)+CPCCD*PCTAMB(J)	00941
AMBDFC(I)=AMBDFC(I)+DFCCD*PCTAMB(J)	00942
340 CONTINUE	00943
TSPMIL=TSPMIL+AMBOPC(I)*TCTLD(I)*COLPCT(I)*CAP(I)	00944
TDFMIL=TDFMIL+AMBDFC(I)*TCTLD(I)*COLPCT(I)*CAP(I)	00945
350 CONTINUE	00946
AVGPCS=TSPMIL/TKWHR	00947
AVDFCS=TDFMIL/TKWHR	00948
AVTCST=(CAPCS1*ANFCR)/(PSIZE*1000.*CAPFAC*8.76) +AVGPCS+AVDFCS+SYS	00949
X1+CSMA1	00950
CALL PBTCD(AVGPCS,AVDFCS,AVTCST)	00951
GO TO 400	00952
370 WRITE(IRITE,371) APPR	00953
371 FORMAT(/,8X,APPROACH=#,F7.1,%, NO CURVES - RUN ABORTED#)	00954
GO TO 400	00955
400 CONTINUE	00956
RETURN	00957
END	00958

SUBROUTINE SUBNDW	00959
COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,CAP(6),TOTLN(5),COLPCT(5),TC	00960
XMIN(6),PCMIN(6),TCMAX(6),PCMAX(6),HRCCF2(6),HRCCF1(6),HRCCFO(6),	00961
XTDR,TWB,RH,TAVH2C,TCBASE,NTAMB,AMBDIC(5),AMBCPC(5),TAMDB(5),TAMW	00962
XB(5),AMRRH(5),TAMRV(5),PCTAMB(5,5),NSYSOP,TDISM,NSPCON,UCVALL,A	00963
XREAC,SPFLOW,NH2C,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHRS,IRITE,IREAD	00964
P1=3.14159	00965
PMPEF=0.8	00966
TOTCS1=1.E3	00967
HDRMAX=1.5	00968
IWL=0	00969
TC=TCMIN(NCAPS+1)	00970
100 CONTINUE	00971
IF(NSPCON-1)30,40,30	00972
40 CALL PAFICST(NCAPS+1,TC,PWCST,DELFC,QREJ)	00973
DT2=(QREJ/SPFLOW)/(EXP(UCVALL*AREAC/SPFLOW)-1.)	00974
DT1=DT2+QREJ/SPFLOW	00975
T1=TC-DT2	00976
IF(NSYSOP-2)44,41,44	00977
41 IF(DT1-(TC-TAVH2C))15,15,42	00978
42 IF(TC-TCMAX(NCAPS+1))13,190,190	00979
13 TC=TC+1	00980
GO TO 40	00981
15 T2=TDISM	00982
APPR=T2-TWB	00983
IF(APPR.LT.7.)GO TO 190	00984
IF(APPR.GT.20.)GO TO 190	00985
RA=T1-T2	00986
IF(RA.LT.10.)GO TO 190	00987
GO TO 46	00988
44 T2=TC-DT1	00989
APPR=T2-TWB	00990
IF(APPR.LT.7.)GO TO 151	00991
IF(APPR.GT.20.)GO TO 190	00992
GO TO 45	00993
30 IF(NSYSOP-2)31,32,31	00994
31 APPR=7.	00995
50 T2=TWB+APPR	00996
IF(TC-T2)151,151,51	00997
32 T2=TDISM	00998
APPR=T2-TWB	00999
IF(APPR.LT.7.)GO TO 190	01000
IF(APPR.GT.20.)GO TO 190	01001
51 DT2=5.	01002
CALL PAFICST(NCAPS+1,TC,PWCST,DELFC,QREJ)	01003
IF(NSYSOP-2)45,46,45	01004
45 CALL COND(TC,T2,QREJ,PWCST,DT2,T1,UA,FLOW,GPM,SYSCST,	01005
* COSPKW)	01006
QREJT=QREJ	01007
GO TO 47	01008
46 CALL COND(TC,TAVH2C,QREJ,PWCST,DT2,T1,UA,FLOW,GPM,SYSCST,	01009
* COSPKW)	01010
QREJT=QREJ*(T1-T2)/(T1-TAVH2C)	01011
47 RA=T1-T2	01012
IF(RA.LT.10.)GO TO 151	01013
WLOAD=1250.	01014
IWL=0	01015
C INITIAL WATER LOADING 1250 LBM/FT2/HR	01016
48 CONTINUE	01017
BSA=FLOW/WLOAD	01018
DIA=SQRTE(4.*BSA/3.14159)	01019
C TAXT = AIR EXIT TEMP - FRAAS + CZISIK	01020

	TAXT=(T1+T2)/2.	01021
	H1=H(TWR)	01022
	H2=H(TAXT)	01023
	AFLR=QREJ/(H2-H1)	01024
	WART=FLCW/AFLR	01025
C	CALC OF CHAR(TOTAL REQUIRED TOWER CHARACTERISTIC) FROM CTI	01026
	T3=T2+0.1*RA	01027
	T4=T2+0.4*RA	01028
	T5=T1-0.4*RA	01029
	T6=T1-0.1*RA	01030
	CO1=WART*RA	01031
	RDH1=1./(H(T3)-H1-0.1*CO1)	01032
	RDH2=1./(H(T4)-H1-0.4*CO1)	01033
	RDH3=1./(H(T5)-H2+0.4*CO1)	01034
	RDH4=1./(H(T6)-H2+0.1*CO1)	01035
	CHAR=(RA/4.)*(RDH1+RDH2+RDH3+RDH4)	01036
C	UNC = CHAR/FT OF PACKING FROM LOWE + CHRISTE	01037
	UNC=0.1*(1./WART)**0.73	01038
	PHT=CHAR/UNC	01039
C	WACT = ACTUAL HUMIDITY	01040
	WACT=RH*(0.622*P(TDB))/(14.696-P(TDB))	01041
	APSAT=(WACT*14.696)/(0.622+WACT)	01042
	DIN=144.*(14.696-APSAT)/(53.35*(TDB+460.))	01043
	DOUT=(144.*(14.696-P(TAXT)))/(53.35*(TAXT+460.))	01044
C	VIN = INLET VELOCITY	01045
	VIN=5.	01046
C	VHDI = INLET VEL HEAD	01047
	VHDI=(VIN**2)*DIN/64.4	01048
	GPHT=(AFLR/3600.)/(PI*DIA*DIN*VIN)	01049
C	SPRAY NOZZLES ASSUMED 4 FT ABOVE PACKING	01050
C	PPK = DEL P OF PACKING (VEL HEADS/FT)	01051
C	ASSUMED LINEAR FUNCTION OF WLOAD - SEE LOWE + CHRISTIE	01052
	PKWA=.5	01053
	PKWB=2.5E-4	01054
	PPK=PHT*(PKWA+PKWB*WLOAD)	01055
C	PSP = DEL P OF SPRAY	01056
	PSP=0.16*(GPHT+4.)*WART**1.32	01057
C	INLET + EXIT TURNING LOSSES + FRICTION LOSS = TPIX VEL HDS	01058
	TPIX=28.5	01059
	TPDP=PPK+PSP+TPIX	01060
	DELP=TPDP*VHDI	01061
	THT=DELP/(DIN-DOUT)	01062
	HDR=THT/DIA	01063
	IF(HDR.LE.HDRMAX)GO TO 120	01064
	WLOAD=.9*WLOAD	01065
	IWL=IWL+1	01066
	IF(IWL.LE.10)GO TO 48	01067
120	HTDIA=THT*DIA	01068
	CAPCOS=3.4E5*(HTDIA**.17)	01069
	CONCR=5.	01070
	TCOUTS=.99674408E1+.24105952E1*H2-.22686654E-1*H2**2 +.10255304E-3	01071
	X*H2**3-.14174090E-6*H2**4	01072
	QLAT=QREJ-AFLR*.24*(TCOUTS-TDB)	01073
	WEVAP=QLAT/970.3	01074
	WBDWN=(.06*QREJ*62.4)/(500.*7.48*(CONCR-1.))	01075
	WNEED=WEVAP+WBDWN	01076
	HPPMP=(GPM*(PHT+4.+GPHT))/(3960.*PMPEF)	01077
	GPCOS=(HPPMP*.7457/(PSIZE*1000.))*PWCST*USEFAC	01078
	DELFC=DELFC*USEFAC	01079
	COSMAI=.001*CAPCOS/(PSIZE*1000.)*.1*CCOS+.01*SYSCST	01080
	TCTCOS=(CAPCOS*ANFCR)/(PSIZE*1000.*CAPFAC*8.76) +GPCOS	01081
	X +COSMAI+SYSCST+DELFC	01082

IF(TOTCOS-TOTCS1)154,156,156	01083
156 IF(NSPCON.EQ.1)GO TO 157	01084
IF(NSYSOP.EQ.2)GO TO 151	01085
APPR=APPR+1.	01086
IF(APPR-20.)50,50,151	01087
157 IF(NSYSOP.EQ.2)GO TO 190	01088
151 TC=TC+1.	01089
IF(TC-TCMAX(NCAPS+1))100,100,190	01090
154 RA1=RA	01091
CHAB1=CHAR	01092
PHT1=PHT	01093
PPK1=PPK	01094
AFLR1=AFLR	01095
APPR1=APPR	01096
HWB1=H1	01097
SYST=SYSCST	01098
CAPCS1=CAPCOS	01099
COSPK1=COSPKW	01100
GPCS1=GPCOS	01101
COSMA1=COSMAI	01102
HPF1=0.0	01103
HPP1=HPP4P	01104
DELF1=DELF	01105
QRJ1=QREJ	01106
QRJT1=QREJT	01107
FLOW1=FLOW	01108
GPM1=GPM	01109
WART1=WART	01110
UA1=UA	01111
WEVAP1=WEVAP	01112
WBDWN1=WBDWN	01113
WNEED1=WNEED	01114
TC1=TC	01115
DIA1=DIA	01116
THT1=THT	01117
TAXT1=TAXT	01118
CPHT1=CPHT	01119
TPDP1=TPDP	01120
DPI=DELP	01121
TOTCS1=TOTCOS	01122
WLOAD1=WLOAD	01123
HOR1=HOR	01124
GO TO 156	01125
190 IF(TOTCS1-1.E3)200,195,200	01126
195 WRITE(IRITE,196)TC,APPR,RA	01127
196 FORMAT(/3X, #FOR THE GIVEN CONDITIONS A SOLUTION CANNOT BE FOUND	01128
XD#./,3X,TC=#,F5.0,# APPR=#,F5.0,# RA=#,F5.0)	01129
GO TO 400	01130
200 CONTINUE	01131
WRITE(IRITE,212)	01132
212 FORMAT(1#,15X, #----- NATURAL DRAFT WET TOWER -----,/, 10X, #	01133
XTHE DESIGN VALUES AND COSTS ARE -#/,/)	01134
CALL PRD51(QRJ1,TC1,HPF1,HPP1,WEVAP1,WBDWN1,AFLR1)	01135
WRITE(IRITE,227)DPI,FLOW1,RA1,APPR1,THT1,DIA1,WLOAD1,CHAR1,PHT1	01136
227 FORMAT(3X, #PRESSURE DROP=#,F5.1,# COND FLOW=#,E9.4,/, 3X#	01137
XRANGE=#,F4.0,# APPROACH=#,F4.0,/,3X#TOWER HEIGHT=#,F6.0,	01138
X # TOWER DIAMETER=#F5.0/# WATER LOADING=#F7.0,# LBM/HR-FT2#	01139
X/ # TOWER CHARACTERISTIC=#F5.2,# PACKING HEIGHT=#F5.2)	01140
IF(NSYSOP-2)230,228,230	01141
228 WRITE(IRITE,229)QRJT1	01142
229 FORMAT(/3X, #Q REJ TOWER=#,E9.4,# BTU/HR#)	01143
230 CALL PRD52(CAPCS1,GPCS1,COSMA1,SYST,DELF1,TOTCS1,COSPK1)	01144

IF (HDR1, LE, HDRMAX) GO TO 140	01145
WRITE (IRITE, 125) HDR1, HDRMAX	01146
125 FORMAT (#0 NOTE--H/D=#F5.2, # WHICH IS GREATER THAN #,	01147
X # H/D MAX=#F5.2//)	01148
140 CONTINUE	01149
WRITE (IRITE, 330)	01150
330 FORMAT (//15X, #VARIABLE AMBIENT CONDITIONS#//)	01151
IF (NTAMB, EQ, 0) GO TO 400	01152
TCPMIL=0.0	01153
TDFMIL=0.0	01154
DO 350 I=1, NCAPS	01155
IF (CAP(I), EQ, 0) GO TO 350	01156
AMBCPC(I)=0.0	01157
AMRDFC(I)=0.0	01158
DO 340 J=1, NTAMB	01159
IF (PCTAMB(I, J), EQ, 0) GO TO 340	01160
TC=TCMIN(I)	01161
NTCCD=0	01162
301 CALL PAF CST(I, TC, PWCST, DFCCD, QREJ)	01163
DT2=(QREJ/FLOW1)/(EXP(UAL/FLCW1)-1.)	01164
DT1=DT2+QREJ/FLCW1	01165
T1=TC-DT2	01166
T2=TC-DT1	01167
IF (NSYSCP-2) 316, 303, 316	01168
316 IF (T2-TAMB(J)) 304, 304, 320	01169
303 IF (T2-TAMRV(J)) 304, 305, 306	01170
305 NTCCD=1	01171
306 T2=TDIS4X	01172
IF (T2.GT. TAMWB(J)) GO TO 320	01173
WRITE (IRITE, 313) TAMWB(J)	01174
313 FORMAT (3X#T DIS MAX LESS THAN (OR =) T WB =# ,F4.0,/, 3X#REQUIR	01175
XES NEGATIVE APPROACH - DISCONTINUING#)	01176
GO TO 400	01177
321 IF (NSYSCP-2) 304, 307, 304	01178
307 WRITE (IRITE, 308) CAP(I), TAMWB(J), TC	01179
308 FORMAT (/8X#FOR CAP =#,F4.2, #, T WB =#,F4.0, #, AND TC =#	01180
X ,F4.0/3X, #T DIS EXCEEDS T DIS MAX - CONTINUING#)	01181
GO TO 315	01182
304 TC=TC+1.	01183
NTCCD=1	01184
IF (TC.LT. TC MAX(I)) GO TO 301	01185
WRITE (IRITE, 309) PC MAX(I), CAP(I), TAMWB(J)	01186
309 FORMAT (/3X, #CONDENSER PRESS MUST EXCEED THE GIVEN MAX OF #/ 8	01187
XX,F4.2, # FOR THE CAPACITY OF #,F4.2, # AT T WET BULB =#,F5.0,/, 3X, #P	01188
XPROGRAM DISCONTINUING#)	01189
GO TO 400	01190
320 WACT=AMBRH(J)*(0.622*P(TAMDR(J)))/(14.696-P(TAMDR(J)))	01191
APSAT=WACT*14.696/(0.622+WACT)	01192
DIN=144.*(14.696-APSAT)/(53.35*(TAMDR(J)+460.))	01193
TAXT=(T1+T2)/2.	01194
RA=T1-T2	01195
H1=H(TAMWB(J))	01196
H2=H(TAXT)	01197
DOUT=(144.*(14.696-P(TAXT)))/(53.35*(TAXT+460.))	01198
AFLR=QREJ/(H2-H1)	01199
VIN=(AFLR/3600.)/(PI*DIA1*CPHT1*DIN)	01200
WART=FLCW1/AFLR	01201
PSP=.16*(CPHT+4.)*WART*.1,32	01202
TPDP=PPK1+PSP+TPIX	01203
VHDI=(VIN**2)*DIN/64.4	01204
THT=(TPDP*VHDI)/(DIN-DOUT)	01205
IF (THT-THT1.GT.5.) GO TO 321	01206

IF (NTCCD.GT.0) GO TO 315	01207
WRITE (IRITE,312) CAP(I),TAMWB(J),TC	01208
312 FORMAT(/BX, #FOR CAP =#,F4.2, #, T WB =#,F5.0, #, AND TC =#,	01209
X F4.0, # PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE#)	01210
IF (DFCCD.GT.0.) DFCCD=0.0	01211
315 CONTINUE	01212
GPCOD=(HPP1*.7457/(PSIZE*1000.))*PWCST	01213
AMBGPC(I)=AMBGPC(I)+GPCOD*PCTAMB(J)	01214
AMBDPC(I)=AMBDPC(I)+DFCCD*PCTAMB(J)	01215
340 CONTINUE	01216
TCPMIL=TCPMIL+AMBGPC(I)*TOTLD(I)*COLPCT(I)*CAP(I)	01217
TDFMIL=TDFMIL+AMBDPC(I)*TOTLD(I)*COLPCT(I)*CAP(I)	01218
350 CONTINUE	01219
AVGPCS=TCPMIL/TKWHRS	01220
AVDFCS=TDFMIL/TKWHRS	01221
AVTCST=(CAPCS1*ANFCR)/(PSIZE*1000.*CAPFAC*8.76) +AVGPCS+AVDFCS+SYS	01222
X1+COSMA1	01223
CALL PRTO (AVGPCS,AVDFCS,AVTCST)	01224
GO TO 400	01225
400 CONTINUE	01226
RETURN	01227
END	01228

SUBROUTINE PAF CST(I,TC,PWCST,DELFC,QREJ)	01229
COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,CAP(6),TOTLn(5),	01230
X COLPCT(5),TCMIN(6),PCMIN(6),TCMAX(6),PCMAX(6),	01231
X HRCOF2(6),HRCOF1(6),HRCOF0(6),TDB,TWB,RH,TAVH2C,TCBASE,	01232
X NTAMB,AMBOFC(5),AMBOPC(5),TAMDB(5),TAMWB(5),AMRRH(5),	01233
X TAMRV(5),PCTAMB(5,5),NBYSOP,TDISMx,NSPCON,UCVAL,AREAC,SPFLCW,	01234
X NH2C,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHR,IRITE,IREAD	01235
HRBASE=HRCOF2(I)*TCBASE**2+HRCOF1(I)*TCBASE+HRCOF0(I)	01236
HEATR=HRCOF2(I)*TC**2+HRCOF1(I)*TC+HRCOF0(I)	01237
QREJ=(HEATR-3*13.)*PSIZE*CAP(I)*1000.	01238
DELHR=HEATR-HRBASE	01239
DELFC=FUCST*DELHR*1.E-5	01240
PWCST=FUCST*HEATR*1.E-5+(CCPKW*ANFCR)/(CAPFAC*8.76)	01241
RETURN	01242
END	01243

	SUBROUTINE COND(TCOND,TIN,QREJ,PWCST,DT2,TCUT,UA,FLOW,GPM,	01244
	* SYSCST,COSPKW)	01245
	COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,CAP(6),TOTLN(5),	01246
	X COLPCT(5),TCMIN(6),PCMIN(6),TCMAX(6),PCMAX(6),	01247
	X HRCOF2(6),HRCOF1(6),HRCOF0(6),TDB,TWB,RH,TAVH2O,TCHASE,	01248
	X NTAMB,AMBDFC(5),AMBGPC(5),TAMDR(5),TAMWB(5),AMRRH(5),	01249
	X TAMRV(5),PCTAMB(5,5),NSYSOP,TDISMN,NSPCON,UCVALL,AREAC,SPFLOW,	01250
	X NH2O,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHR,IRITE,IHEAD	01251
	PMPEF=.8	01252
	IF(NSPCON.EQ.1)GO TO 30	01253
C	VARIATION OF HEAT TRANSFER COEFFICIENT, UALL, WITH TYPE	01254
C	OF WATER	01255
	IF(NH2O)20,10,15	01256
10	UALL=340.	01257
	GO TO 25	01258
15	UALL=420.	01259
	GO TO 25	01260
20	UALL=250.	01261
25	CONTINUE	01262
	DT1=TCOND-TIN	01263
	TCUT=TCOND-DT2	01264
	DELT=TCUT-TIN	01265
C	ALOG MEAN TEMPERATURE DIFFERENCE, LMTD	01266
	DTLGM=(DT1-DT2)/(ALOG(DT1/DT2))	01267
	ACOND=QREJ/(DTLGM*UALL)	01268
	UA=UALL*ACOND	01269
	CONCST=20.*(ACOND*.05)**.9	01270
C	65 PERCENT INCREASE IN MATERIAL COSTS IF SALT WATER USED	01271
	IF(NH2O.LT.0)CONCST=CONCST*1.65	01272
	FLOW=QREJ/DELT	01273
	GPM=FLOW/(8.34*60.)	01274
C	ASSUME 35 FT OF HEAD	01275
	CHEAD=35.	01276
	PMPCST=(GPM*CHEAD*.7457*PWCST)/(3960.*PMPEF*PSIZE*1000.)	01277
C	1 DOLLAR PER GPM FOR COST OF PUMPS	01278
	COSPKW=(CONCST+1.*GPM)/(PSIZE*.E3)	01279
	SYSCST=(COSPKW*ANFCR)/(CAPFAC*8.76)+PMPCST	01280
	GO TO 50	01281
30	UA=UCVALL*AREAC	01282
	FLOW=SPFLOW	01283
	GPM=FLOW/(8.34*60.)	01284
	SYSCST=0.0	01285
50	RETURN	01286
	END	01287

SUBROUTINE PRDTS1 (QREJ, TC, HPF, HPP, WEV, WBD, AFLR)	01288
COMMON PSIZE, CCPKW, ANFCR, FUCST, NCAPS, CAP (6), TCTLN (5), COLPCT (5), TC	01289
XMIN (6), PCMIN (6), TCMAX (6), PCMAX (6), HRCCF2 (6), HRCCF1 (6), HRCCF0 (6),	01290
XTDR, TWB, RH, TAVH2O, TCBASE, NTAMB, AMBDFC (5), AMRQPC (5), TAMDB (5), TAMW	01291
XB (5), AMBRH (5), TAMRV (5), PCTAMB (5, 3), NSYSOP, TDISHX, NSPCON, UOVALL, A	01292
XREAC, SPFLOW, NH2O, WIDTH, PRPAGR, CAPFAC, USEFAC, TKWHR, IRITE, IREAD	01293
WEVCFS=WEV/244700.	01294
WBDCFS=WBD/244700.	01295
WRITE (IRITE, 10) QREJ, TC, HPF, HPP, WEVCFS, WEV, WBDCFS, WBD, AFLR	01296
10 FORMAT (/, 3X, #Q REJECT =#, E9.4, # BTU/HR AT T CONDENSEQ =#, F5.0	01297
X, /, 3X, #FAN POWER =#, E9.4, # HP PUMP POWER =#, E9.4, # HP, /, 3X, #	01298
*H2O EVAP =#, E9.4, # CFS (#, E9.4, # LB/HR) #/	01299
* # H2O BLOWDOWN =#, E9.4, # CFS (#, E9.4, # LB/HR) #/	01300
* # AIR FLOW RATE =#, E9.4, # LB/HR #)	01301
RETURN	01302
END	01303

SUBROUTINE PRDTS2(CAPCOS,OPCOS,COSMAI,SYSCOS,DELFC,TOTCOS,COSPKW)	01304
COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,CAP(6),TOTLN(5),COLPCT(5),TC	01305
XMIN(6),PCMIN(6),TCMAX(6),PCMAX(6),HRCOF2(6),HRCOF1(6),HRCOF0(6),	01306
XTDR,TWB,RH,TAVH2C,TCBASE,NTAMB,AMBDFC(5),AMBOPC(5),TAMDB(5),TAMW	01307
XB(5),AMBRH(5),TAMRV(5),PCTAMB(5,5),NSYSCP,TDISMx,NSPCON,UQVALL,A	01308
XREAC,SPFLOW,NH2O,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHR,IPITE,IREAD	01309
WRITE(IRITE,10) CAPCOS,COSPKW,OPCOS,COSMAI,SYSCOS,DELFC,TOTCOS	01310
10 FORMAT(10 CAPITAL COST =,E9.4, DOLLARS// CONDENSER AND PUMP	01311
*COST =,E9.4, DOLLARS/KW// OPERATING COST =,	01312
X F6.3, MILLS/KW-HR// 3X, MAINTENANCE COST =,F6.3, MILLS	01313
X/KW-HR// 3X, CONDENSER SYSTEM COST =,F6.3, MILLS/KW-HR// 3X,	01314
X DIFFERENTIAL FUEL COST =,F6.3, MILLS/KW-HR// 3X, TOTAL SYS	01315
X TEM COST =,F6.3, MILLS/KW-HR//	01316
RETURN	01317
END	01318

SUBROUTINE PNTCD(GPCDD,DFCDD,TCDD)	01319
COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,CAP(6),TOTLN(5),COLPCT(5),TC	01320
XMIN(6),PCMIN(6),TCHAX(6),PCMAX(6),HRCCF2(6),HRCCF1(6),HRCCFO(6),	01321
XTDB,TWR,RH,TAVH2O,TCBASE,NTAMB,AMBDFC(5),AMBOPC(5),TAMDB(5),TAMW	01322
XB(5),AMBRH(5),TAMRV(5),PCTAMB(5,5),NSYSCP,TDISUX,NSPCCN,UCVALL,A	01323
XREAC,SPFLOW,NH2O,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHRS,IRITE,IREAD	01324
WRITE(IRITE,10)GPCDD,DFCDD,TCDD	01325
10 FORMAT(/5X,WITH THE VARIOUS AMBIENT TEMPERATURES#/,	01326
X 5X,THE COSTS ARE #,/,	01327
X 3X,OPERATING COST =#.F6.3,# MILLS/KW-HR#/,	01328
X 3X,DIFFERENTIAL FUEL COST =#.F6.3,# MILLS/KW-HR#/,	01329
X /,3X,TOTAL SYSTEM COST =#.F6.3,# MILLS/KW-HR#)	01330
RETURN	01331
END	01332

FUNCTION H(I)
H =21.572142-.93539227*T+.28365243E-01*T**2 -.26605772F-03*T**3+
X.12608996E-05*T**4
RETURN
END

01333
01334
01335
01336
01337

FUNCTION P(T)
P = .16818166E-1 + .14461089E-2 * T + .83460247E-5 * T**2 + .4987537E-6
X * T**3 - .20658843E-9 * T**4 + .22620224E-10 * T**5
RETURN
END

01338
01339
01340
01341
01342

DATA SUBD1

200	150	.12	10	1000	5		
100	80	60	25	0			
5150	1750	800	700	360			
80	70	50	30	15			
3	3	4	3	3	5		
150	100	100	100	100	150		
350	400	400	450	450	350		
150	250	350					
7987	8037	8153					
100	200	300					
7974	8025	8174					
100	200	300	350				
8055	8195	8430	8543				
100	200	300					
8828	9381	9815					
100	200	300					
0	0	0					
150	200	250	300	350			
8000	8009	8042	8089	8151			
85	75	75	1.5	10	4000	-1	3
70	80	85					
60	70	70					
60	65	70					
10	10	10					
4000	4000	4000					
25	25	50					
30	30	40					
40	30	30					
50	25	25					
00	00	100					
2000	2	1	85	350	2.76E5	4.2E7	
1		1	1	1			

DATA SUBD2

200	150	.12	10	1000	5		
100	80	60	25	0			
5150	1750	800	700	360			
80	70	50	30	15			
3	3	4	3	3	5		
150	100	100	100	100	150		
350	400	400	450	450	350		
150	250	350					
7987	8037	8153					
100	200	300					
7974	8025	8174					
100	200	300	350				
8055	8195	8430	8543				
100	200	300					
8828	9381	9815					
100	200	300					
0	0	0					
150	200	250	300	350			
8000	8009	8042	8089	8151			
85	75	75	1.5	10	4000	0	3
70	80	85					
60	70	70					
60	65	70					
10	10	10					
4000	4000	4000					
25	25	50					
30	30	40					
40	30	30					
50	75	25					
00	00	100					
2000	0	1		350	2.76E5	4.2E7	
1	1	1	1	1			

DATA SUBD3

200	150	.12	10	5000	5		
100	80	60	25	0			
5150	1750	800	700	360			
80	70	50	30	15			
3	3	4	3	3	5		
150	100	100	100	100	150		
350	400	400	450	450	350		
150	250	350					
7987	8037	8153					
100	200	300					
7974	8025	8174					
100	200	300	350				
8055	8195	8430	8543				
100	200	300					
8828	9381	9815					
100	200	300					
0	0	0					
150	200	250	300	350			
8000	8009	8042	8089	8151			
85	75	75	1.5	10	4000	0	3
70	80	85					
60	70	70					
60	65	70					
10	10	10					
4000	4000	4000					
25	25	50					
30	30	40					
40	30	30					
50	25	25					
00	00	100					
2000	2	0	85				
1		1	1	1			

DATA SUBD4

200	150	.12	10	5000	5		
100	80	60	25	0			
5150	1750	800	700	360			
80	70	50	30	15			
3	3	4	3	3	5		
150	100	100	100	100	150		
350	400	400	450	450	350		
150	250	350					
7987	8037	8153					
100	200	300					
7974	8025	8174					
100	200	300	350				
8055	8195	8430	8543				
100	200	300					
8828	9381	9815					
100	200	300					
0	0	0					
150	200	250	300	350			
8000	8009	8042	8089	8151			
85	75	75	1.5	10	4000	0	3
70	80	85					
60	70	70					
60	65	70					
10	10	10					
4000	4000	4000					
25	25	50					
30	30	40					
40	30	30					
50	25	25					
00	00	100					
2000	0	0					
1	1	1	1	1	1		

1	Accession Number	2	Subject Field & Group	SELECTED WATER RESOURCES ABSTRACTS INPUT TRANSACTION FORM
			Ø5E	

5	Organization
	Dynatech R/D Company

6	Title
	"A Survey of Alternate Methods for Cooling Condenser Discharge Water -- System Selection, Design, and Optimization"

10	Author(s)	16	Project Designation
	Smith, N. Maulbetsch, John S.		FWQA Contract 12-14-477 Project # 16130 DHS
		21	Note

22	Citation
	Water Pollution Control Research Series 16130 DHS 01/71

23	Descriptors (Starred First)
	*Power - electric; *Cost analysis; Condensers; *Heat exchangers; *Water cooling; Thermal power; economics

25	Identifiers (Starred First)

27	Abstract
	A computer program is described for calculation of both cooling system and power plant cost and the determination of the minimum total cost for a given set of parameters. To this end the effect of various design parameters have been studied to determine which have significant effects on the performance of the various cooling schemes and which are important to power plant costs. Design equations based on these parameters are incorporated into a computer program through which the minimum total cost is calculated.

This report was submitted in fulfillment of Contract No. 12-14-477 under the sponsorship of the Federal Water Quality Administration. (Rainwater - EPA/WQO)

Abstractor	Frank H. Rainwater	Institution	EPA/WQO/National Thermal Pollution Research Program
WR 102 (REV JULY 1969) WRSIC		SEND TO: WATER RESOURCES SCIENTIFIC INFORMATION CENTER U.S. DEPARTMENT OF THE INTERIOR WASHINGTON, D. C. 20240	